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Externalizing Psychopathology and Behavioral Disinhibition: Working Memory Mediates Signal Discriminability and Reinforcement Moderates Response Bias in Approach-Avoidance Learning

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Abstract

Research suggests reduced working memory capacity plays a key role in disinhibited patterns of behavior associated with externalizing psychopathology. In this study, participants (N=365) completed two versions of a Go/No-Go mixed-incentive learning task that differed in the relative frequency of monetary rewards and punishments for correct and incorrect active-approach responses, respectively. Using separate structural equation models for conventional (hit and false alarm rates) and Signal Detection Theory (signal discriminability and response bias) performance indices, distinct roles for working memory capacity and changes in payoff structure were found. Specifically, results showed that (1) working memory capacity mediated the effects of externalizing psychopathology on false alarms and discriminability of Go versus No-Go signals; (2) these effects were not moderated by the relative frequency of monetary rewards and punishments; (3) the relative frequency of monetary rewards and punishments moderated the effects of externalizing psychopathology on hits and response bias for Go versus No-Go responses; and (4) these effects were not mediated by working memory capacity. The findings implicate distinct roles for reduced working memory capacity and poorly modulated active approach and passive avoidance in the link between externalizing psychopathology and behavioral disinhibition.

Keywords

Externalizing psychopathology; behavioral disinhibition; working memory capacity; Go/No-Go learning; Signal Detection Theory

Externalizing psychopathology encompasses a range of co-occurring psychiatric disorders, including substance use disorders, childhood oppositional defiance/conduct disorder, and adult antisocial personality (Krueger et al., 2002). A characteristic common to different types of externalizing psychopathology is high levels of behavioral disinhibition (Bogg & Finn, 2010; Finn, Mazas, Justus & Steinmetz, 2002; Gorenstein and Newman, 1980). Behavioral disinhibition can be described as an ongoing pattern of failing to inhibit, or continuing to engage in, certain appetitive behaviors that have previously led to aversive

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consequences. For instance, those with alcohol dependence continue to drink to excess in spite of repeatedly experiencing such negative outcomes as loss of friends, spouse, health, and job (Finn 2002; Finn et al., 2005). Similarly, despite negative outcomes such as trouble with the law, job loss, loss of friends, physical injuries, and interpersonal violence, individuals with antisocial personality continue to engage in behavior that violates the rights of others, the law, and social norms (Lykken, 1995). Research suggests that behavioral disinhibition is associated with individual differences in working memory processes, such as reduced executive attention and short-term activation capacities (Bogg & Finn, 2010; Finn, 2002; Finn et al., 2009) as well as motivational processes, such as hypersensitivity to reward or appetitive consequences and a hyposensitivity to punishment or aversive consequences (Finn, 2002; Finn, et al., 2002; Patterson & Newman, 1993; Fowles, 1980; 1984). The present study builds from this research by examining the extent to which working memory processes and motivational processes interact to influence behavioral disinhibition in externalizing psychopathology.

The overarching goal of the current study was to further our understanding of the interrelationships among those working memory processes and motivational processes thought to contribute to behavioral disinhibition in externalizing psychopathology. This was accomplished by examining the direct, indirect, and conditional effects of a latent externalizing psychopathology factor (Finn et al., 2009; Krueger et al., 2002) on separate latent factors of executive working memory capacity and short-term memory capacity (Bogg & Finn, 2010; Engle, Tuholski, Laughlin, & Conway, 1999; Finn et al., 2009), and performance indices from two motivationally distinct versions of a Go/No-Go mixed-incentive measure of approach-avoidance learning (Go/No-Go: Finn et al., 2002; Newman et al., 1985).

Consistent with previous research, Signal Detection Theory (Greene & Swets, 1966; Smillie & Jackson, 2006) was used as a mathematical framework for modeling two key mechanisms involved in Go/No-Go decision-making under uncertainty, (i) perceptual sensitivity (e.g., the ability to learn to discriminate among active-approach versus passive-avoidance signals) and, (ii) response bias (e.g., tendency to engage in active-approach versus passive-avoidance behavior). A key facet in the kind of approach-avoidance learning modeled by Go/No-Go tasks is the process of learning to discriminate between the Go and No-Go signals; better discrimination reflects superior self-regulation. Another important facet in this kind of approach-avoidance learning is response bias; some individuals have a general tendency to respond (Go), while others have a general tendency to inhibit their response (No Go); a Go response bias reflects a general readiness to act in a specific context, while a No-Go response bias reflects a more cautious approach to making decisions in a specific context. Finally, the current study manipulated the incentive structure (reinforcement schedule) of the Go/No-Go task to examine whether making rewards (appetitive consequences) or punishments (aversive consequences) more probable would differentially affect Go/No-Go performance as a function of degree of externalizing psychopathology.

Externalizing Psychopathology and Behavioral Disinhibition

Externalizing disorders, such as substance use disorders, conduct disorder, and antisocial personality are highly covariant (Finn et al., 2009; Krueger et al., 2002). Research has shown that a single latent dimension, referred to as externalizing psychopathology, captures a large proportion of the covariation among substance use problems, conduct problems, adult antisocial problems, and disinhibited personality trait indicators (Finn et al., 2009; Krueger & Markon, 2006). Numerous studies show an association between laboratory measures of the processes that contribute to behavioral disinhibition and different types of externalizing disorders, including substance use disorders, conduct disorder, and antisocial personality (e.g., Finn et al., 2002; Bobova et al., 2009; Cantrell et al., 2008; Iacono et al., 1990; Newman et al., 1985; Newman, Patterson, Howland & Nichols, 1990). In fact, recent research suggests that disinhibitory processes are associated with the covariance among different types of externalizing disorders, rather than being uniquely associated with any one externalizing disorder (Bobova et al., 2009; Cantrell et al., 2008).

Aside from self-report approaches, researchers have used a variety of experimental tasks to assess the processes that contribute to behavioral disinhibition in externalizing psychopathology, such as Go/No-Go learning, delay discounting, Iowa Gambling, and stop-signal tasks (Barkley, 1997; Bobova et al., 2009; Cantrell et al., 2009; Finn, 2002; Nigg, 2000). In the current study, a Go/No-Go mixed-incentive learning task (Go/No-Go: Newman et al., 1985) is used as an analog for behavioral inhibition in approach-avoidance contexts. On this task, those with high levels of externalizing psychopathology typically commit more passive-avoidance errors (errors of commission or false alarms) compared to those with low levels of externalizing problems (Finn, Justus, Mazas & Steinmetz, 2002, 1999; Helmers, Young & Pihl, 1995; Newman, et al., 1985; Newman & Kosson, 1986; Newman et al., 1990; Newman & Wallace, 1993; Patterson & Newman, 1993). In general, these findings are thought to provide evidence that difficulty with learning to inhibit reward-seeking responses that have previously resulted in some aversive outcome, such as loss of money or electric shock (i.e., poor passive-avoidance learning), represents a key psychological diathesis to disinhibitory/externalizing psychopathology (Gorenstein & Newman, 1980; Lykken, 1957; Sher & Trull, 1994; Smith & Newman, 1990), assessed here as a latent factor of externalizing psychopathology.

Because thorough reviews of this research can be found elsewhere (Newman & Lorenz, 2003), it is emphasized here that passive-avoidance errors in the Go/No-Go task operationalize behavioral disinhibition in the form of difficulty modulating conflict between two prepotent motivational systems; one governing the tendency to seek out or actively approach appetitive outcomes and the other governing the tendency to withdraw from or passively avoid aversive outcomes (Gray, 1987; 1982). Based on this reinforcement sensitivity perspective (Pickering & Gray, 2001), previous research has implicated specific incentive-motivation mechanisms as candidate sources of the difficulties with passive-avoidance learning apparent in externalizing psychopathology, such as a hypersensitivity to reward conditioning stimuli or strong active-approach tendencies, as well as a hyposensitivity to punishment conditioning stimuli or weak passive-avoidance tendencies (Finn, 2002; Finn, et al., 2002; Patterson & Newman, 1993; Fowles, 1980; 1984).

The current research offers an alternative conceptualization of the psychological mechanisms that may support poor passive-avoidance learning in externalizing psychopathology. Signal Detection Theory (SDT: Greene & Swets, 1966) is used as a framework for Go/No-Go task performance because it makes a clear mathematical distinction between perceptual sensitivity (e.g., the ability to learn to discriminate among active-approach versus passive-avoidance signals) and response bias (e.g., tendency to engage in active-approach versus passive-avoidance) mechanisms in the process of decision making under uncertainty. To determine the utility of using the SDT framework to model Go/No-Go task performance, participants completed two motivational distinct conditions; one where the probability for reward was greater than punishment, and another where the probability of punishment was greater than reward. As described in more detail below, these experimental manipulations were used to test the more general prediction that changes in incentive or payoff structure would selectively influence bias for Go/No-Go responses but not discriminability for Go/No-Go signals.

Externalizing Psychopathology and Reduced Working Memory Capacity

Reduced capacity in executive cognitive processes that are not directly motivational in nature, but nevertheless critical to adaptive self-regulation, may contribute to difficulty learning from the aversive consequences associated with abusing psychoactive chemicals and engaging in socially inappropriate behavior (Barkley, 2001; Bechara & Martin, 2004; Finn, 2002; Finn, et al., 2002; Giancola, Zeichner, Yarnell, & Dickenson, 1996; Hinsen, Jameson, & Whitney, 2003; Iacono, et al., 1999; Maccoon & Newman, 2006). For example, a number of studies have shown that reduced working memory capacity is associated with a range of different externalizing disorders, such as substance use disorders, childhood conduct disorder, and adult antisocial personality (Aytaclar, Tarter, Kirisci, & Lu 1999; Finn & Hall, 2004; Finn et al., 2009; Harden & Pihl, 1995; Nigg, 2000; Poon, Ellis, Fitzgerald, & Zucker, 2000). More recently, Finn and colleagues (Bogg & Finn, 2010; Finn et al., 2009) found reduced working memory to be associated with the covariance among latent indicators of externalizing psychopathology (Bogg & Finn, 2010; Finn et al., 2009), as well as indicators of impulsive/sensation-seeking and antisocial/unconventional personality traits (Bogg & Finn, 2010). Furthermore, modeling results showed the association between latent constructs and reduced executive cognitive ability was neither specific to any single externalizing problem nor disinhibitory trait indicator (Bogg & Finn, 2010; Finn et al., 2009).

Working memory has been described as a limited capacity information processing system comprised of interdependent component processes related to the executive control of attention and the active maintenance of short-term memory (Adrande, 2001; Baddeley 1986, 2000; Baddeley & Loggie, 1999; Baddeley & Hitch, 1974; Conway, 2005; Miyake & Shah, 1999). Together, these component processes are responsible for activating, maintaining, and utilizing context-relevant information over brief periods of time and despite interference from context-irrelevant information (Baddeley & Hitch, 1974; Colom, Abad, Rebollo & Shih, 2006; Conway & Engle 1994; Engle, et al., 1999; Unsworth & Engle, 2007a; 2007b). More generally, working memory is believed to represent a supervisory or executive control system that guides cognition and self-regulation, especially under conditions that call for the inhibition of automatic cognitive operations, prepotent motivational impulses, or habitual behavioral routines (Barkley, 1997; 2001; Finn & Hall, 2004; Finn, 2002; Oberauer, 2002; Kimberg, D'Esposito & Farah, 1997; Kane et al., 2004).

Recent modeling research supports the utility of a two-factor structure of working memory (Conway et al., 2005; Kane, Bleckley, Conway & Engle, 2001; Unsworth & Engle, 2007a; Unsworth & Engle, 2008); one that distinguishes short-term memory capacity (as indicated by simple memory span tasks) from the total capacity in executive attention and short-term memory (as indicated by complex memory span tasks). Overall, this work has shown that working memory capacity is a reliable predictor of capabilities in other higher-order cognitive domains, such as language comprehension, general intelligence, complex reasoning, contingency learning, and the inhibition of prepotent or automatic responses (Daneman & Carpenter, 1980; Unsworth & Engle, 2007b; Kane, et al., 2001; Kane et. al., 2004). These studies illustrate that working memory plays an important role in the executive or effortful control over ongoing cognitive and behavioral processes.

When taken together, both the clinical and cognitive research suggest that, because it is critical to higher-order executive control, reduced working memory capacity may partly be responsible for the patterns of behavioral disinhibition associated with externalizing psychopathology. Specifically, studies imply reduced working memory capacity could contribute to difficulty activating, maintaining, and utilizing past aversive experiences as a means to modulate ongoing appetitive behavior (i.e., passive-avoidance learning). Despite the intuitive appeal of this postulate, there remains little definitive evidence regarding the specific role, if any, played by working memory capacity in tasks that are designed to assess approach-avoidance learning. In part, the current study addressed this question by examining two key hypotheses. The first was that working memory capacity is directly related to optimal approach-avoidance learning in situations of uncertainty and motivational conflict. The second was that the association between externalizing psychopathology and difficulties with approach-avoidance learning under uncertainty and motivational conflict would be indirect via reduced working memory capacity.

The Present Study

The primary aim of the present study was to test specific predictions regarding the direct, indirect, and conditional effects of a latent externalizing psychopathology factor on several measures of working memory capacity and Go/No-Go task performance. Based on previous work by Newman and colleagues (Gorenstein & Newman, 1980; Newman, et al., 1985; Newman & Kosson, 1986; Newman & Wallace, 1993; Patterson & Newman, 1993; Yechiam et al., 2006), externalizing psychopathology was expected to be associated with poor passive-avoidance learning. Consistent with other work by Finn and colleagues (Finn, 2002; Finn et al., 2002; 1999), working memory capacity also was expected to mediate the association between externalizing psychopathology and poor active-approach and passive-avoidance learning.

The second aim of this study was to investigate the utility of using mathematical frameworks to describe, compute, and assess Go/No-Go task performance (Gomez, Ratcliff & Perea, 2007; Smillie & Jackson, 2006; Yechaim et. al., 2006). Specifically, the present study includes analyses based on the univariate case of SDT (Macmillan & Creelman, 1991; Green & Swets, 1966). The main advantage of using the SDT framework, is that it allowed us to estimate the contribution of perceptual (i.e., signal discriminability) independent of decisional (i.e., response bias) mechanisms in the process of Go/No-Go task performance. In line with previous SDT analyses of decision making under uncertainty and motivational conflict, we expected to find that monetary payoff manipulations would selective influence participants' bias for Go/No-Go responses, but not their discriminability for Go/No-Go signals (Busemeyer & Townsend, 1993; Smillie, Dalgleish, & Jackson, 2007; Smillie & Jackson, 2006).

To address these aims, established methods for quantifying statistical mediation and moderation (Baron & Kenny, 1986; Judd, Kenny, & McClelland, 2001; Preacher, Rucker, & Hayes, 2007) were used to test the *a priori* hypotheses that: (1) externalizing psychopathology is associated with reduced working memory capacity; (2) externalizing psychopathology is associated with (a) greater false alarms, (b) fewer hits, (c) poor signal discriminability, and (d) failure to modulate active-approach responding; (3) working memory capacity is associated with (a) fewer false alarms, b) greater hits, (c) better signal discriminability, and (d) adaptive modulation of active-approach responding; (4) the effects of externalizing psychopathology on measures of Go/No-Go performance are (a) mediated by working memory capacity and (b) moderated by changes in the relative frequency of monetary rewards and punishments.

Method

Participants

Sample characteristics—The sample represents a subset of participants who took part in a larger study on the cognitive (Finn et al., 2009), decision making (Cantrell et al., 2008; Bobova et al., 2008), and personality (Bogg & Finn, 2010) correlates of externalizing psychopathology. Further details regarding study recruitment, screening, and inclusion/ exclusion criterion can be found in Finn et al. (2009).

The sample (N=365) consisted of primarily young adults (mean age = 21.87 ± 2.8) with roughly equal gender representation (52.1% female). At the time of assessment, participants completed (13.8 ± 2.0) years of education on average and had a mean IQ of (105 ± 9.5), as measured by the Shipley Institute of Living Scale (Zachary, 1986). The majority of participants were Caucasian (78.9%) with the remainder of the sample comprising African-American (12.3%), Asian-American (5.5%), Hispanic-American (2.5%), and other (0.8%) ethnicities. Twenty-five percent of the sample did not meet *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition* (DSM-IV; American Psychiatric Association, 1994) criteria for a history of substance use or antisocial behavior problems.

Assessment Materials and Laboratory Tasks

Semi-structured interviews—History of alcohol dependence and lifetime alcohol, marijuana, and other drug problems were ascertained with the Semi-Structured Assessment for the Genetics of Alcoholism (SSAGA; Bucholz et al., 1994). History of conduct disorder and lifetime childhood conduct disorder and adult antisocial behavior problems also were assessed with the SSAGA. Severity of lifetime problems was indicated by participants' total number of positive responses to SSAGA interview questions relating to five domains: alcohol, marijuana, other drugs, childhood conduct disorder, and adult antisocial behavior.

Short-term memory capacity—Short-term memory capacity was assessed with the digits forward (DFS) and (DBS) backward span subtests of the Wechsler Adult Intelligence Scale-Revised (WAIS; Wechsler, 1981) and the letter-number (LNS) subtest of the WAIS-III (Wechsler, 1997). The DFS, DBS, and LNS tasks operationalize short-term memory capacity as the total number of to-be-remembered items of varying list sizes that can be held in mind and manipulated in some way. They are termed simple span tasks (Conway et al., 2005) because they involve immediate recall of to-be-remembered list items. In subsequent analyses, the capacity of short-term memory represented the covariance in DFS, DBS, and LNS performance, as indicated by participants' total accuracy across the various list lengths of each task.

Executive working memory capacity—Executive working memory capacity was assessed with the operation-word span test (OWS; Conway & Engle, 1994) and a modified auditory consonant delay test (ACT; Brown, 1958; Finn et al., 2009). The OWS and ACT tasks operationalize working memory capacity as the total number of to-be-remembered list items that can be held in mind while performing a secondary cognitive task. These tasks are termed complex span tasks (Conway, et al., 2005) because they involve both a primary memory task, such as recalling word or letter strings of various sizes in order of presentation, and the performance of a secondary cognitive task, such as solving a mathematical operation or counting backwards by threes for a predetermined length of time. In subsequent analyses, the capacity of executive working memory represented the covariance in OWS and ACT, as indicated by participants' total accuracy across the various list lengths and delay intervals of each task.

Go/No-Go mixed-incentive learning task—The current study used a repeated measures design in which each participant completed two versions of a standard Go/No-Go mixed-incentive learning task (Newman, et al., 1990; 1985; Newman & Kosson, 1986). The two versions, hereafter referred to as reinforcement schedule (RS) conditions, differed with respect to the relative frequency of monetary rewards and punishments for correct and incorrect active-approach responding. In each RS condition, the stimulus set consisted of eight two-digit numbers with four of the numbers signaling the availability of monetary reward (go signal: S+) and four signaling the availability of monetary punishment (no-go signal: S−). On each trial, the numerical stimulus was presented on a computer monitor for a fixed 750 millisecond self-terminating response window. Participants were required to either respond by pressing the computer keyboard spacebar (go response: R+) during this response window or refrain from pressing the spacebar (no-go response: R−) and allow the response window to time-out. The stimulus set was counterbalanced for odd and even numbers above and below fifty and a different set of numbers were used for each Go/No-Go task RS condition. In each RS condition, a total of 56 stimulus-response trials were administered in a pseudorandom trial sequence with the constraint that the four S+ and four S− stimuli appeared in every epoch of eight trials and no more than two S+ or S− stimuli were presented in succession.

Before starting each RS condition, participants were instructed to use trial-and-error to learn which numbers required pressing the spacebar and which numbers required withholding that response. They also were instructed that visual feedback would be provided on some trials. Specifically, that a green screen indicating "Win $0.51" might appear for pressing the spacebar in response to an S+ number and a red screen indicating "Lose $0.51" might appear for pressing the spacebar in response to an S− number. Corrective auditory feedback was provided on every trial using a low tone for correct (R+|S+) responses and high tone for incorrect (R+|S−) responses, which, in SDT terminology, represents hits and false alarms, respectively. No feedback was provided for correctly (R−|S−) and incorrectly (R−|S+) inhibited behavioral responses, which, in SDT terminology, represents correct rejections and misses respectively. Participants were informed that they would be able to "keep all monetary winnings" and would not "lose any of their own money on the task;" they also were told that they "only had a limited time to respond to each cue" and therefore, "should attempt to respond as quickly and as accurately as possible."

Although the same experimental procedure was used in each of the two Go/No-Go task RS conditions, the relative frequency of receiving monetary reward or punishment and corresponding visual feedback differed in each RS condition. In the high-reward/low-punishment (HRLP) RS condition, participants received a monetary reward (with visual feedback) after every hit and a monetary punishment (with visual feedback) after every third false alarm. In the low-reward/high-punishment (LRHP) RS condition, participants received monetary reward (with visual feedback) after every third hit and monetary punishment (with visual feedback) after every false alarm. Note that varying the incentive structure in this manner (i.e., ratio of 3:1 favoring either rewards or punishments) affects the amount that can be won or lost in each RS condition. At one extreme, an individual pressing the spacebar on all 56 trials in the HRLP RS condition would receive (28*1.00)*($0.51) = $14.28 for hits, and lose (28*0.33)*($0.51) = $4.76 for false alarms, with a net gain of $14.28 − $4.76 = $9.52. Using a similar strategy in the LRHP RS condition would yield (28*0.33)*($0.51) = $4.76 for hits, and lose (28*1.00)*($0.51) = $14.28 for false alarms, with a net loss of $4.76 − 14.28 = −$9.52. In general, the incentive structure favors monetary gain in the HRLP RS condition and monetary loss in the LRHP RS condition. RS condition was counterbalanced across participants such that roughly half of the participants were administered the HRLP first.

Signal Detection Theory (SDT) model of Go/No-Go performance—Figure 1 shows a graphical representation of the SDT model of approach (Go) – avoidance (No Go) signal discrimination and response bias estimates of Go/No-Go learning task performance. The current application of the SDT framework relies on the basic assumption that the univariate Gaussian model of Yes-No discrimination (Greene & Swets, 1966;Macmillan & Creelman, 1991;Macmillan, 2005) is appropriate for modeling performance on Go/No-Go mixed-incentive learning tasks. Explicitly, it is assumed that internal representations of the No-Go signals and Go signals can be characterized by two independent probability density functions that are equal-variance normally distributed along a single decision axis.

In the current study, the discriminability (d') parameter was conceptualized as an estimate of the ability to learn to discriminate signals to actively approach reward from those to passively avoid punishment. More generally, the d' parameter is considered a measure of the cognitive or perceptual mapping of the approach and avoidance signals to their appropriate active and passive responses. In Figure 1, the d' parameter is given by the absolute difference or “absolute strengths” between internal representations of the No-Go and Go signals; it is calculated by taking the difference of transformed pHT and pFA quantities. The response bias (log(β)) parameter, was conceptualized as an estimate of the tendency to engage in active-approach and passive-avoidance responding. More generally, the log(β) is considered a measure of the motivational valence or relative decisional weights attributed to active-approach and passive-avoidance responses. In Figure 1, the log(β) is given by the relative heights or “ratio of strengths” of the No-Go and Go response tendencies for a given value of d'; it is calculated by taking the product of the d' and decisional criterion (*C*) parameters.

One important strength of the SDT framework (Green & Swets, 1966; see also Townsend, Hu, & Kadelc, 1988; Busemeyer & Townsend, 1993) stems from the prediction that, while salience manipulations (e.g., brightness or size) influence the decision-makers' ability to discriminate among stimulus classes (i.e., signal discriminability), stimulus presentation or payoff probability manipulations (e.g., how often certain stimuli are presented or the benefits and costs associated with correct or incorrect choices) influence the decision-makers' preference for certain decisions (i.e., response bias). In the current study, the HRLP and LRHP RS conditions were designed so as to manipulate the benefits (i.e., monetary rewards) and costs (i.e., monetary punishments) associated with correct (i.e., hits) and incorrect (i.e., false alarms) active-approach responses. Thus, the HRLP and LRHP RS conditions were expected to selectively influence participants' tendency to engage in active-approach (i.e., R+) relative to passive-avoidance (i.e., R−) responding (i.e., response bias), not their ability to learn to discriminate signals to actively approach (i.e., S+) reward from those to passively avoid (i.e., S−) punishment (i.e., signal discriminability). As shown in Figure 1, participants were expected to adopt a more “liberal” use of active-approach responses (i.e., strong tendency for “Go” decisions) in the HRLP RS condition and a more “conservative” use of active-approach responses (i.e., weaker tendency for “Go” decisions) in the LRHP RS condition.

Procedure

Participants read and signed an informed consent to participate, were free to refuse any procedure, and were paid $7.00 per hour. The diagnostic interview was administered first, followed by an interspersed ordering of the Go/No-Go tasks and working memory measures. The total time of assessment was approximately 3–4 hours spread out over three testing sessions.

Data Analyses

The present study used Confirmatory Factor Analyses (CFA) and Structural Equation Modeling (SEM) to test specific predictions regarding inter-associations among a latent externalizing psychopathology (EXT) factor, a latent executive working memory capacity (EWMC) factor, a latent short-term memory capacity (STMC) factor, and separate conventional (hit rates and false alarm rates) and SDT (discriminability and response bias) measures of Go/No-Go task performance. Consistent with previous research (Bogg & Finn, 2010, Krueger et al., 2002), latent EXT was indicated by the sum of positive responses to SSAGA interview questions pertaining to lifetime problems with alcohol (ALC), illicit drugs (DRG: sum of marijuana and other drug problem counts), and adult antisocial behavior (AAB: sum of childhood conduct and adult antisocial personality disorder problem counts). The SSAGA problem counts were Blom transformed prior to dimensional analyses (Krueger et al., 2002; van den Oord et al., 2000). Latent EWMC was indicated by performance accuracy on the OWS and ACT complex span tasks. Latent STMC was indicated by performance accuracy on the DFS, DBS, and LNS simple span tasks.

Based on the predications of the SDT framework and previous work by Smillie and Jackson (2006), a parallel set of dimensional analyses were used to further examine the selective influences (i.e., moderating effects) of monetary reward and punishment relative frequency on the association between latent EXT and Go/No-Go performance, as measured by conventional (hit and false alarm rates) and SDT model estimates (response bias and discriminability). Specifically, simple regression analyses (Judd, Kenny, & McClelland, 2001) were used to test the hypotheses that: (1) the association between latent EXT and Go/No-Go response bias measures is moderated by RS condition; but, (2) the association between latent EXT and Go/No-Go signal discriminability is not moderated by RS condition. In these analyses, externalizing psychopathology was quantified by a unidimensional externalizing factor score. This factor score was obtained using the Blom-transformed symptom count variables (ALC, DRG, and AAB) and extracted with the maximum likelihood method as implemented in SPSS version 16 (SPSS Inc., Chicago, IL).

The initial CFA was used to compare the relative fit of a two-factor model of EWMC and STMC components in span task performance (Engle et al., 1999) to an alternative model where the controlled executive attention component of complex span tasks is partitioned from the common short-term memory component of both simple and complex span tasks (Kane et al., 2004). Subsequently, a two-stage SEM path fitting procedure was used to test the hypotheses that: (1) latent EXT has an effect on Go/No-Go performance; and (2) latent EWMC and latent STMC mediates the effects of latent EXT on Go/No-Go performance. Separate SEM analyses were conducted for pHT and pFA (i.e., conventional measures) and d' and β (i.e., SDT measures). Evidence for mediation was determined by testing the null hypothesis that the bootstrapped (k=20,000) and bias-corrected (BC) 95% confidence intervals (CI) around model estimates of direct and indirect effect s included zero (Preacher et al., 2007). Moderation effects also were examined within the two-stage SEM path fitting procedure. Evidence for moderation was determined by examining whether the magnitudes of direct or indirect effects were affected by the relative frequency of monetary rewards and punishments. That is, whether significance of a given stage one or two model path was exclusive to either the HRLP or LRHP RS conditions (Preacher et al., 2007). Model paths were freely estimated in the CFA and two-stage SEM path fitting procedure.

The chi-square (χ^2) and Bayesian Information Criterion (BIC) statistics were used as the primary arbiters of goodness of fit among competing measurement and path models. A non-significant ($p > .05$) χ^2 test statistic suggests excellent data-model fit. The BIC aided in selecting which model among competing models reproduced the observed variances and covariances with the fewest estimated parameters (i.e., the most parsimonious model). Lower BIC values indicate better comparative fit in terms of the odds of one model being superior to others (Raftery, 1995). Specifically, a difference in BIC of 10 points between two given models indicates that the odds are approximately 150:1 that the model with the lower BIC value provides a better fit than the model with the higher BIC values (Raftery, 1995). The Root Mean Square Error of Approximation (RMSEA) also is reported, but is not used for comparative purposes. Rather it is used to quantify the closeness of fit of each model in relation to its degrees of freedom (Browne & Cudeck, 1993) such that values approaching zero are indicative of better fit. Browne and Cudeck (1993) advise that a RMSEA value of approximately .08 indicates a reasonable error of approximation. Similarly, the Normed Fit Index (NFI; Bentler & Bonett, 1980) is reported. NFI scores range from 0–1, where a score of .85, for example, means that 85 % of the saturated model is reproduced by a tested model. A NFI score above .90 suggests adequate fit.

Results

Descriptive Statistics

Sample means, standard deviations, and correlations for the indicators of latent EXT, EWMC, and STMC as well as the conventional (pHT and pFA) and SDT (d' and log(β)) measures of Go/No-Go performance for HRLP and LRHP RS conditions are shown in Table 2. Univariate and multivariate measures of skew and kurtosis for each variable are also reported in Table 2. Multivariate outliers were identified prior to analyses using the Mahalanobis distance (d) statistic (Tabachnick & Fidell, 1996) with criterion $\chi^2_{(10)} = 29.59$, $p < .001$. Data for 4 subjects were excluded from the sample (N=361) using this criterion[1]. Multivariate kurtosis was .63, 3.27, −.51, .70 for the models shown in Figure 4, panels A–D, respectively.

Is lifetime externalizing psychopathology associated with reduced working memory capacity and approach-avoidance learning difficulty?

Confirmatory Factor Analyses (CFA)

As reported in Table 1, CFA was used to compare the relative fits for a two-factor (Engle et al., 1999) and a common variance (Kane et al., 2001;2004) model of simple- and complex-span task performance. In both models, correlated errors were allowed for the DFS and DBS simple-span tasks because these indicators share common methodological variance. The latent EXT factor also was included in both models to control for individual differences in working memory task performance associated with covarying ALC, DRG, and AAB problems. Model comparisons revealed that both the two-factor (Figure 3A) and common variance (Figure 3B) models fit well. However, it was ultimately the two-factor model that provided the most parsimonious fit to the data, as indicated by a lower BIC score (see Table 2). Shown in Figure 3A, this measurement model comprised 3 indicators of latent EXT (Cronbach's alpha = .86), 2 indicators of latent EWMC (Cronbach's alpha = .80), and 3 indicators of latent STMC (Cronbach's alpha = .79).

The inter-correlations among latent factors in Figure 3A all significant at p < .001, illustrating that (1) EXT was negatively associated with both EWMC and STMC; and (2) EWMC and STMC were positively associated with one another. This pattern of results suggests that, while capacity in the executive attention and short-term activation stores of working memory are positively associated, these capacities are reduced in those with more severe lifetime externalizing problems. Note that the covariance structure and size of the inter-correlations among EXT, EWMC, and STMC in Figure 4A are similar to the regression path weights drawn in Finn et al., (2009, p. 108). Moreover, the covariance structure and size of the inter-correlation between EWMC and STMC in Figure 4 also resemble the models drawn in Engle et al., (1999, p. 325; also see Unsworth & Engle 2007a).

[1]For the SEM shown in Figure 5c, an additional subject was identified (d=29.75, p = .001), but subsequently retained in the model because removing this subject's data neither improved model fit ($\chi^2_{(26)} = 36.74$; p = .08; NFI = .97; RMSEA = .03; BIC = 207.44) nor substantively changed the patterns of significance in this mediation model.

Conventional measures of Go/No-Go performance

Simple regression analyses showed higher EXT factor scores predicted (1) greater false alarms in both the HRLP ($\beta = .12$, $p < .05$) and LRHP ($\beta = .18$, $p < .001$) RS conditions, and (2) fewer hits in the HRLP ($\beta = -.17$, $p < .005$) RS condition, but not the LRHP ($\beta = .07$, ns) RS condition. Analogous to previous research, these data suggest that individuals with more severe lifetime externalizing problems are prone to difficulties with passive-avoidance learning and these effects are robust against changes in the relative frequency of monetary rewards and punishments; and, that individuals with more severe lifetime externalizing problems have difficulty with active-approach learning, but only when rewards were more probable than punishments.

Signal Detection Theory measures of Go/No-Go performance

Simple regression analyses showed that latent EXT factor scores predicted (1) lower discriminability in both the HRLP ($\beta = -.21$. $p < .001$) and LRHP ($\beta = -.22$, $p < .001$) RS conditions, and (2) higher log (β) in the HRLP ($\beta = .19$, $p < .001$) RS condition, but not the LRHP ($\beta = .06$, ns) RS condition. Figures 2A and 2B show scatter plots and linear regression lines with 95% CIs for the effects of EXT on d' (Figure 2A) and log (β) (Figure 2B) as a function of the HRLP (circles) and LRHP (triangles) RS conditions. These data illustrate that the relative frequency of monetary reward and punishment (1) does not affect the association between higher EXT and poor Go/No-Go signal discriminability, as illustrated by the parallel regression lines, but (2) does affect the association between higher EXT and modulating Go/No-Go response bias, as illustrated by the non-parallel regression lines towards the lower end of the EXT dimension. Consistent with expectations, these data also suggest that change in the payoff structure does not affect the association between EXT and signal discriminability. Data also suggest that, while change in the payoff structure has selective influence over the response bias of individuals with less severe lifetime externalizing problems, it does not have selective influence over the response bias of those with more severe lifetime externalizing problems.

Is the association between externalizing psychopathology and approach-avoidance learning difficulty mediated by working memory capacity?

In Figure 4, the unmediated and mediated effects[2] of EXT on Go/No-Go performance showed a similar pattern of results as the conventional and SDT measures. Separate SEM path analyses were conducted for conventional measures (panel A: pFA and panel B: pHT) and SDT (panel C: d' and panel B: log(β)) measures of Go/No-Go performance. As reported in Table 1, two path models were evaluated for each SEM: one with the unmediated the effects of EXT on Go/No-Go measures for the HRLP and LRHP RS conditions; and another with effects of EXT on Go/No-Go measures for the HRLP and LRHP RS conditions mediated by EWMC and STMC. In Table 1, all models fit well to the data as indicated by NFI > .97 and RMSEA < .05. With the exception of the model in Figure 4A, all SEMs produced a non-significant χ^2 value ($p > .05$), indicating that the actual variance-covariance matrices and model-estimated variance-covariance matrices were not significantly different.

In Figure 4, the overall patterns of results for the significance (bolded path weights) of the unmediated (path weights shown in parentheses) direct effects of EXT on Go/No-Go measures of performance were consistent with those found in the CFA and linear regression analyses. For conventional measures, EXT predicted higher pFA in both the HRLP and

[2]Modification indices (Arbuckle, 1997) for regression weights were evaluated after mediated effects models were fitted. Thresholds for modification indices were set at 6.64, which would amount to a significant change in $\chi^2_{(1)}$ at $p < .01$. No single manifest variable was found to be significant predictor at this criterion. This means that no single indicator of latent EXT, latent EWMC, or latent STMC was associated with working memory or Go/No-Go task performance above and beyond their respective latent factors.

LRHP (panel A), as well as lower pHT in the HRLP RS condition, but not in the LRHP RS condition (panel B). For the SDT measures, EXT predicted lower discriminability in both the HRLP and LRHP RS conditions (panel C), as well as higher log (β) in the HRLP RS condition, but not in the LRHP RS condition (panel D). In Figure 4, also note that the patterns of significance for the direct effects of EXT on latent EWMC and latent STMC as well as the correlated errors between latent EWMC and latent STMC are consistent with the measurement model shown in Figure 3A[3].

Bootstrapped 95% CI tests of the indirect effects revealed that EWMC mediated the effects of EXT on pFA in both the HRLP ($\beta = .17$, $p < .001$; lower bound = .11; upper bound = .25) and LRHP ($\beta = .15$, $p < .001$, lower bound = .09; upper bound = .23) RS conditions. This is illustrated in Figure 4A, by (1) the non-significant (non-bolded path weights shown outside of the parentheses) direct effects of EXT on pFA in both the HRLP and LRHP RS conditions and (2) the significant (bolded path weights) direct effects of EWMC, but not STMC, on pFA in both the HRLP and LRHP RS conditions. Bootstrapped 95% CI tests of the indirect effects also revealed that neither EWMC nor STMC mediated the effects of EXT on pHT in either the HRLP ($\beta = -.06$, ns, lower bound = −.13, upper bound = .01) RS condition or the LRHP ($\beta = -.05$, ns, lower bound = −.12, upper bound = .02) RS condition. This is illustrated in Figure 4B, by (1) the significant direct effect of EXT on pHT in the HRLP RS condition, despite (2) the significant direct effect of STMC on pHT in both the HRLP and LRHP RS conditions. These data suggest that reduced working memory capacity transmits (i.e., mediates or accounts for) the association between lifetime externalizing problems and difficulty with passive-avoidance learning, but not difficulty with active-approach learning.

Bootstrapped 95% CI tests of the indirect effects revealed that both EWMC and STMC mediated the effects of EXT on d' in both the HRLP ($\beta = -.16$, $p < .001$, lower bound = −.24; upper bound = −.10) and LRHP ($\beta = .16$, $p < .001$, lower bound = −.24; upper bound = −.10) RS conditions. This is illustrated in Figure 4C, by (1) the non-significant direct effects of EXT on d' in both the HRLP and the LRHP RS conditions, and (2) the significant direct effects of EWMC and STMC on d' in both the HRLP and LRHP RS conditions. Bootstrapped 95% CI tests of the indirect effects also revealed that neither EWMC nor STMC mediated the effects of EXT on log(β) in either the HRLP ($\beta = .03$, ns, lower bound = −.04; upper bound = .09) RS condition or the LRHP ($\beta = .04$, ns, lower bound = −.04; upper bound = .11) RS condition. This is illustrated in Figure 4D, by (1) the significant direct effect of EXT on log(β) in the HRLP RS condition, despite (2) the significant direct effect of STMC on log(β) in both the HRLP and LPHR RS conditions. Similar to the findings with conventional measures, these data suggest that reduced working memory capacity transmits (i.e., mediates or accounts for) the association between lifetime externalizing problems and difficulty with Go/No-Go signal discriminability, but not failing to modulate Go/No-Go response bias.

> Are the interrelationships among externalizing psychopathology, working memory capacity, and approach-avoidance learning moderated by the relative frequency of monetary rewards and punishments?

In Figure 4, the relative frequency of monetary rewards and punishments had similar effects on the association between EXT and the conventional and SDT measures of Go/No-Go performance. Shown in Figures 4A and 4C, the mediating effects of EWMC and STMC in the association between EXT and passive-avoidance errors (pFA: panel A) as well as and

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[3]While the measurement models are drawn with bi-directional arrows so as to represent the more general non-causal relationship between latent EXT and latent working memory capacity, it is necessary to assume causality in the meditational model so as to test for the indirect effects of latent EXT on Go/No-Go performance.

poor discriminability (d': panel C) were not moderated by RS condition. Note that the bootstrapped indirect effects of EXT on pFA and d' via working memory capacity were significant in both the HRLP and LRHP RS conditions. By contrast, Figures 4B and 4D show that moderating effects of RS condition in the association between effects of EXT on pHT (panel B) and log(β) (panel D) that were moderated by RS condition also were not mediated by working memory capacity. Note that the bootstrapped indirect effects of EXT on pHT and log(β) via working memory capacity were non-significant in both the HRLP and LRHP RS conditions. Overall, these data suggest that distinct cognitive processes (i.e., signal discriminability mediation by working memory capacity) and motivational process (i.e., response bias moderation by change in payoff structure) contribute to the association between more severe lifetime externalizing problems and difficulty with approach-avoidance learning.

Discussion

The overarching goal of the current study was to further our understanding of the interrelationships among those working memory processes and motivational processes thought to contribute to behavioral disinhibition in externalizing psychopathology. The basic premise of the present study was that reduced capacity in the executive attention and short-term activation processes of working memory plays an intermediate role in the disinhibited patterns of behavior associated with externalizing psychopathology. Specifically, if persons with a chronic, severe, and co-occurring history of externalizing psychopathology are prone to behavioral disinhibition, then reduced working memory capacity is likely to be responsible for some of this relationship. Moreover, while working memory capacity may mediate the association between externalizing psychopathology and difficulties learning to discriminate between active-approach and passive-avoidance signals, the relative frequency of monetary rewards and punishments are likely to moderate individuals' tendency to engage in active-approach and passive-avoidance responses.

Externalizing psychopathology is associated with both reduced working memory capacity and difficulty with approach-avoidance learning

Results of the current study showed externalizing (EXT) psychopathology was associated with poor performance on various measures of working memory and Go/No-Go mixed-incentive learning. As in previous work by Finn and collaborators (Bogg & Finn, 2010; Finn et al., 2009), a single latent EXT factor predicted reduced capacity in separate latent measures of executive working memory (EWMC) and short-term memory (STMC). Consistent with this previous work, the current study found that no single indicator of externalizing psychopathology was associated with measures of working memory and Go/No-Go task performance above and beyond that of the latent EXT factor. Furthermore, no single indicator of working memory capacity was associated with Go/No-Go task performance above and beyond that of the latent EWMC and STMC factors.

Results using conventional estimates of Go/No-Go performance (i.e., hit and false alarm rates) further demonstrated that externalizing psychopathology was associated with difficulty learning to passively avoid aversive outcomes. Specifically, regressions analyses showed that persons with more a chronic and severe history of externalizing problems had greater difficulty with passive-avoidance learning, regardless of whether monetary reward was more probable than punishment (e.g., HRLP RS condition) or monetary reward was less probable than punishment (e.g., LRHP RS condition). Notably, analyses also revealed externalizing psychopathology to be associated with active-approach learning difficulty, but only in the HRLP RS condition. Overall, these findings are consistent with previous work by Newman and colleagues (see Newman & Lorenz, 2003 for review), and support the broad hypothesis that difficulty with approach-avoidance response modulation is a core feature in syndromes of behavioral disinhibition, assessed here as a latent factor of externalizing psychopathology.

Separate discriminability and response bias mechanisms contribute to approach-avoidance learning under two motivationally distinct RS conditions

Results based on the SDT model of Go/No-Go task performance addressed how cognitive and motivational mechanisms contribute to behavioral disinhibition in externalizing psychopathology. Here, as in previous work by Smillie and others (Smillie, Dalgleish, & Jackson, 2007; Smillie & Jackson, 2006), the SDT framework was shown to be successful in distinguishing individual differences in approach-avoidance signal learning (signal discriminability – d') from individual differences in approach-avoidance response tendencies (response bias – log(β)). Specifically, results showed externalizing psychopathology to be associated with difficulty learning to discriminate between signals to actively approach reward from those to passively avoid punishment (lower d' values), and a failure to adaptively modulate bias for active-approach responding as a function of the relative frequency of monetary rewards and punishments (no difference in log(β) across RS conditions). Similar to Smillie and Jackson (2006), these findings are interpreted to mean that the SDT prediction for a selective influence of payoff manipulations on response bias does not hold for individuals with a history of chronic and severe externalizing psychopathology. Specifically, our data suggest that increased externalizing psychopathology is associated with a rigid and inflexible behavioral repertoire; one that is resistant to change, even if the motivational context calls for a more behaviorally disinhibited pattern of responding.

Working memory capacity mediates the association between externalizing psychopathology and difficulty with approach-avoidance learning

Consistent with Finn and colleagues (Finn, 2002; Finn & Hall, 2004; Finn et al, 2002), results with conventional Go/No-Go measures suggested that reduced working memory capacity was responsible for the negative association between EXT and difficulties with passive-avoidance learning (i.e., high false alarm rates). Specifically, results showed the poor-passive avoidance learning associated with EXT was transmitted through reduced capacity in the executive attention component (i.e., EWMC factor), and not the short-term memory component (i.e., STMC factor), of working memory. In contrast to these findings, SEM analyses showed the association between externalizing psychopathology and difficulty with active-approach learning in the HRLP RS condition was not indirect via working memory capacity. However, results did show that STMC, and not EWMC, was associated with better active-approach learning in both RS conditions.

Bootstrapped 95% CI tests of the indirect effects of working memory capacity on the association between externalizing psychopathology and SDT measures of Go/No-Go performance parallel those found for conventional measures in two key ways. First, reduced working memory capacity was shown to be responsible for the association between EXT and poor signal discriminability (lower d' values). However, unlike the false alarm rates, the association between EXT and low d' were shown to be indirect via both EMWC and STMC. This is likely due to the fact that both hit and false alarm rates are used to compute d' estimates. Specifically, EWMC and STMC were associated with Go/No-Go signal discriminability because EWMC was associated with fewer No-Go signal false alarms and STMC was associated with more Go signal hits. Second, analogous to the findings for hit rates, neither EWMC nor STMC mediated the association between EXT and response bias (higher log(β) values) in the HRLP RS condition. Although the effects of EXT on response bias were not indirect via working memory capacity, STMC was associated with lower log(β) values (i.e., more Go or active-approach responses) in both RS conditions. Notably, EWMC was not associated with log(β) values. This finding could be interpreted to mean that the short-term memory component, not the controlled attention component of working memory, keeps sampled information active in mind for use in behavioral regulation; and, moreover, this capacity is independent of an individuals' history with externalizing psychopathology.

The relative frequency of monetary rewards and punishments moderates the association between externalizing psychopathology and difficulties with approach-avoidance response modulation

Results based on moderation analyses addressed when cognitive and motivational mechanisms contribute to behavioral disinhibition in externalizing psychopathology. Specifically, analyses with both conventional and SDT framework measures revealed that (1) the mediated effects of EXT on passive-avoidance learning and discriminability via working memory capacity were not moderated by experimental RS conditions, and (2) the moderated effects of EXT on active-approach learning and response bias via experimental RS conditions were not mediated by working memory capacity. The lack of moderated mediation suggests that the difficulty with approach-avoidance learning in externalizing psychopathology due to reduced working memory capacity is largely robust against changes in the motivational context. By contrast, the lack of mediated moderation in our analyses suggests the difficulty with approach-avoidance response modulation in externalizing psychopathology is largely unrelated to reduced working memory capacity.

In the current study, only direct effects were shown to be moderated by changes in the relative frequency of monetary rewards and punishments. Specifically, the direct effect of EXT on active-approach learning and response bias (stage one of path fitting procedure) were exclusive to the HRLP RS condition. Moreover, persons with fewer lifetime externalizing problems shifted to a more optimal “liberal” response bias (a response strategy that maximizes payoffs in the long-run) in the HRLP RS condition, while those with more lifetime externalizing problems did not. When contrasted with the results of regression analyses, these moderation effects suggest that changes in the probability of rewards and punishments did not selectively influence the response biases or behavioral tendencies of those who occupy the upper end of the externalizing continuum. These data could be interpreted to mean that, unlike those with a low to moderate history, those with a chronic and severe history of externalizing psychopathology fail to recognize and adapt to changes in the motivational context, even if the situation calls for them to be more behaviorally disinhibited.

Notably, our payoff manipulations also showed evidence of moderating the direct effects of STMC on response bias independent of EXT. Specifically, when controlling for the negative effect of EXT on STMC, the magnitude of the association between STMC and response bias was twice as strong in the LRHP RS condition as it was in the HRLP RS condition. This suggests that STMC has a more general role in regulating bias for active-approach responding, especially when the risks associated with incorrect responses outweigh the benefits associated with correct responses. This also could be interpreted to mean that short-term memory plays a larger role in the coordination and planning of behavioral responding when the long-term prospects for aversive outcomes are greater than those for appetitive outcomes.

Dual cognitive and motivational mechanisms contribute to the patterns of behavioral disinhibition associated with externalizing psychopathology

Consistent with Finn and collaborators (Bogg & Finn, 2010; Finn & Hall, 2004; Finn, 2002; Finn et al., 2002; 2009), results of the mediation and moderation analyses are interpreted as evidence that both reduced working memory capacity and poorly modulated approach-avoidance tendencies contribute to behavioral disinhibition in externalizing psychopathology. As it pertains to the more general role of working memory in approach-avoidance learning, our study added to the extant literature by revealing distinct roles for working memory component processes. Specifically, the current findings suggest that the executive attention (i.e., EWMC) component of working memory may aid in the process of resolving approach-avoidance conflict by keeping a robust mental account of past experiences with aversive consequences and effectively utilizing these event-behavior relationships so as to inhibit prepotent motives for appetitive stimulation. Our findings also suggest that the short-term memory (i.e., STMC) component of working memory could aid in the storage of behaviorally relevant information by keeping the features of appetitive stimuli active in mind for comparison to the features of aversive stimuli. This interpretation is analogous with the emerging dynamic control view of the working memory system; one where a primary memory component (i.e., EWMC) interacts with a secondary memory component (i.e., STMC) as if to: (1) discriminate between multiple sources of information by assigning priority or cognitive weights to information as a function of their contextual relevance; (2) actively maintain these weights in mind as templates for comparison to incoming streams of information; and (3) monitor, update, and, if need be, inhibit memory traces for use in the coordination and planning of contextually appropriate behavioral responding (Finn, 2002; Unsworth and Engle, 2007b; 2008).

As it pertains to externalizing psychopathology, we further interpret the current study results as consistent with the proposal that separate, but interrelated, cognitive and motivational processes contribute to difficulty with behavioral inhibition (Gray, pp 167). Specifically, our findings suggest that disinhibited responses in the presence of negative or aversive stimuli may arise out of both inadequate learning of reinforcement contingences (e.g., poor signal discriminability) as well as inefficient sampling of information from the reinforcement context (e.g., inflexible response bias). The current research added to this reinforcement sensitivity perspective in two ways. First, the association between externalizing psychopathology and difficulty with the discrimination learning of approach-avoidance signals was shown to be mediated by working memory capacity. This implies that internal representations of approach-avoidance reinforcement signals are generated by an executive cognitive process, a capacity that is reduced in those with more chronic and severe externalizing psychopathology. Second, the association between externalizing psychopathology and difficulty enacting context-appropriate behavioral response was not shown to be mediated by working memory capacity. This implies that the assignment of optimal motivational valences to approach-avoidance responses are generated by context-dependent affective processes, a capacity that is highly rigid, inflexible, and resistant to experimental control in those with more chronic and severe externalizing psychopathology.

Limitations and Future Directions

This study was not without limitations and caveats. Most notable among them is our use of a cross-sectional design. In particular, our models treat the latent externalizing factor as a predictor of working memory capacity and approach-avoidance learning, which implies a causal prediction of reduced executive cognitive ability and behavioral disinhibition, respectively. A longitudinal design would be better suited for determining the causal associations among these domains. Such a design would (1) better account for cumulative development and transactions among externalizing psychopathology and working memory capacity; and (2) establish the predictive ordering of these constructs. In addition to the limitation of a cross-sectional design was the targeted sampling scheme used in the current study. Although the sampling procedure was successful in recruiting disinhibited individuals, the resulting sample does not reflect the prevalence of these trait levels or problems in a `natural' population. A large-scale, population-based longitudinal design would be better suited to uncover causal associations as well as identify possible developmental pathways to externalizing psychopathology (Bogg & Finn, 2010).

A second drawback was that our SDT analysis of Go/No-Go performance does not directly generalize to individual differences in trial-by-trial learning. Unlike other computational models of Go/No-Go task performance (Yechiam et al., 2006; Gomez, Ratcliff, & Parea, 2007), the approach taken here did not account for the sequential learning of active-approach and passive-avoidance signals. The SDT model used here is deterministic (i.e., static) in that the internal signal-response distributions assumed to underlie Go/No-Go hit and false alarm rates also are assumed to be generated over numerous independent trials. More formal models of Go/No-Go task performance, such as the cue dependant learning model (Yechiam et al.,, 2006) and response time diffusion model (Gomez, Ratcliff & Parea, 2007), may be better suited for studying the component processes that underlie Go/No-Go learning. In addition to the limitation of our static SDT approach, we did not incorporate estimates of participant response times. Although the static SDT model was shown to be adequate for estimating perceptual and decisional characteristics of performance, the model does not account for possible speed/accuracy tradeoffs. Along these lines, a goal in future research is to investigate the generalizability of a dynamic SDT model of Go/No-Go task performance; one that consists of model parameters for reinforcement learning and speed/accuracy tradeoffs, as well as signal discriminability and response bias.

Aside from these limitations, this study makes three novel and important contributions to the literature on the association between externalizing psychopathology and behavioral disinhibition. First, to our knowledge, this is the first large-scale study to demonstrate that performance on laboratory measures of working memory capacity, which are not designed to assess incentive motivation, can account for the association between a latent EXT factor and performance on Go/No-Go tasks, which were designed to assess approach-avoidance incentive motivation. Of particular importance was finding evidence for the differential roles of working memory component processes in approach-avoidance learning. Second, the results further show that the SDT model of Go/No-Go performance is a reliable framework for quantifying the extent to which experimental manipulations affect behavioral inhibition. Specifically, while changes in the relative frequency of monetary rewards and punishments did not affect individuals' Go/No-Go signal discrimination, it did selectively influence their Go/No-Go response bias. Third, the results suggest that the reduced working memory capacity is an intermediate mechanism in difficulty with active approach and passive avoidance. Specifically, while working memory did not mediate the association between externalizing psychopathology and failures to modulate Go/No-Go response bias as a function of motivational context, it did mediate the association between externalizing psychopathology and difficulty with Go/No-Go signal discrimination regardless of motivational context. Taken together, these findings implicate separate, but interrelated, roles for reduced working memory capacity and difficulties with approach-avoidance response modulation in the disinhibited patterns of behavior associated with externalizing psychopathology.

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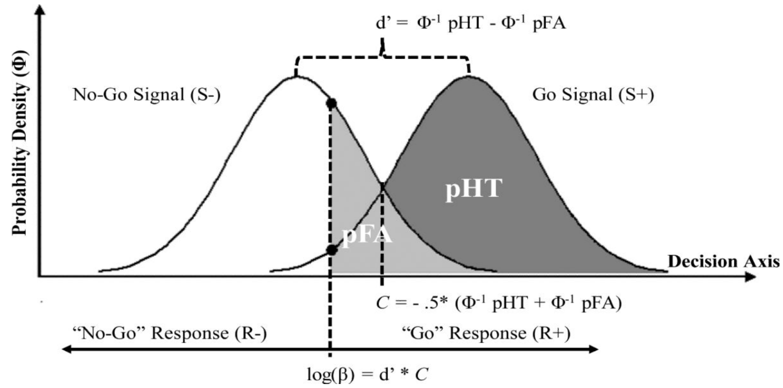

Figure 1.

Signal Detection Theory model of Go/No-Go discrimination. Hypothetical No-Go (S−) and Go (S+) signal distributions are assumed to be equal-variance normally distributed along a single "No-Go" (R−) and "Go" (R+) response decision axis. As demonstrated in Macmillan and Creelman, (1990), the SDT model parameters signal discriminability (d'), decisional criterion (*C*), and response bias (β) can be calculated by applying the inverse normal density function transformation (IDF: Φ^{-1}) to the conditional probability of hits (pHT = R+|S+) and false alarms (pFA = R+|S−). These conditional probabilities were calculated by dividing the observed number of hits and false alarms by 28, which was the maximum number possible hits and false alarms. The d' parameter is calculated by taking the difference of the IDF transformed pHT and pFA quantities. The *C* parameter is calculated by taking the negative of one half of the sum of the IDF transformed pHT and pFA quantities; it is then used as an intermediate quantity in calculating the log-likelihood ratio criterion. The log-likelihood ratio criterion or response bias measure log(β) is calculated by taking the product of d' and *C* parameters.

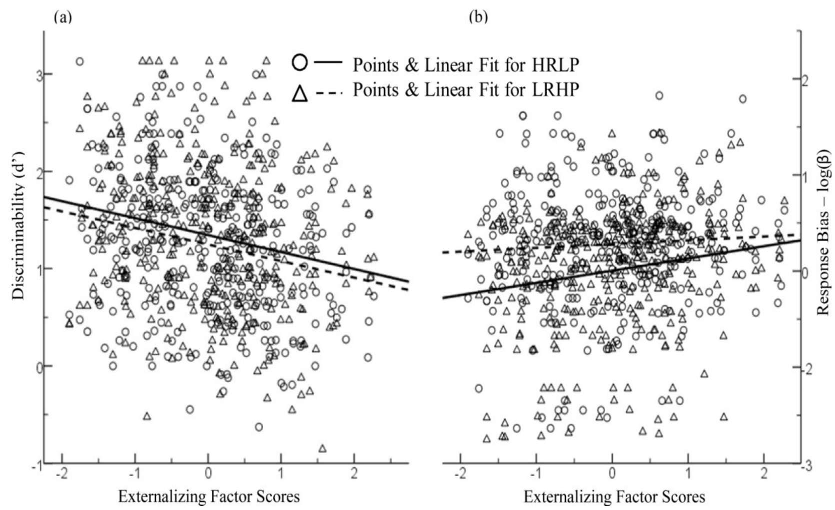

Figure 2.
Effects of latent externalizing problems (EXT) factor on discriminability (d') (panel A) and response bias (log(β)) (panel B)measures of Go/No-Go performance for the high-reward/low-punishment (HRLP, circles) and low-reward/high-punishment (LRHP, triangles) conditions. Linear regression model fits for the (HRLP, solid lines) and (LRHP, hashed lines) shown with 95% confidence intervals (CI).

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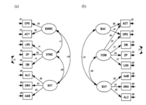

Figure 3.
Confirmatory factor analyses of competing two-factor (panel A) and common variance (panel B) measurement models of simple and complex working memory span task performance. Latent factors: EWMC = executive working memory capacity (EWMC), STMC = short-term memory capacity; EAC = executive attention capacity; COM = common variance; EXT = externalizing psychopathology. Manifest variables: ACT = Auditory Consonant Trigram; OWS = Operation Word Span; DFS = Digits Forward Span; DBS = Digits Backward Span; LNS = Letter Number Sequencing; ALC = Alcohol ; DRG = Illicit Drugs; AAB = Adult antisocial Behavior. All standardized regression weights and correlation coefficients are significant at p < .001.

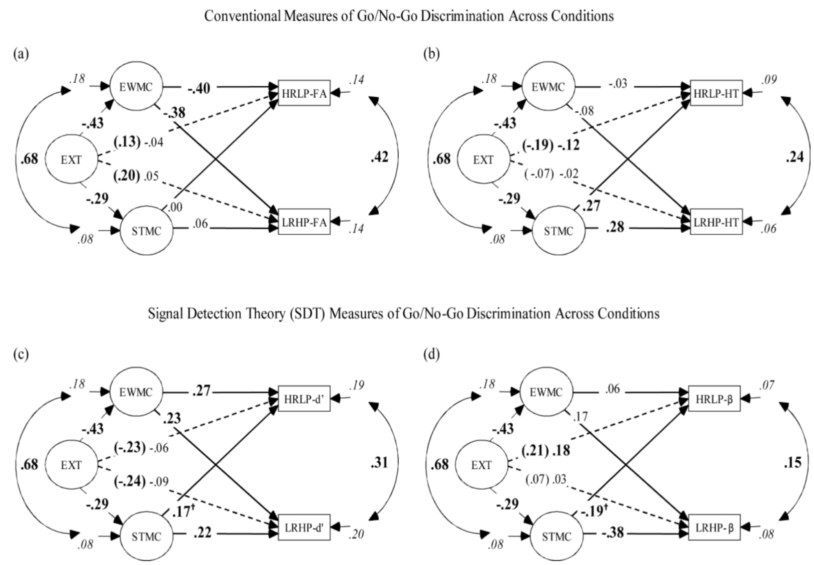

Figure 4.

Structural models used to test for meditation and moderation effects of latent working memory factors (EWMC – executive working memory capacity and STMC = short-term memory capacity) and experimental condition (HRLP = high-reward/low-punishment and LRHP = low-reward/high punishment), respectively, on the association between externalizing psychopathology (EXT) and separate measures of Go/No-Go performance: pFA = false alarms (panel A), pHT = hits (panel B), d' = discriminability (panel C), and β = response bias (panel D). Model parameters were freely estimated. Unmediated effects of latent EXT on Go/No-Go measures are shown in parentheses and corresponding path drawn with dotted lines. All path coefficients represent standardized regression weights with significant paths bolded ($p < .05$, †$p < .07$). Squared multiple correlations are the italicized quantities located behind latent and manifest variables. A) latent EXT effects on pFA are mediated by latent EWMC in both HRLP and LRHP conditions and these indirect effects are not moderated by condition. B) latent EXT effects on pHT are not mediated by latent working memory factors and these direct effects are moderated by condition. C) latent EXT effects on d' are mediated by both latent EWMC and latent STMC in both HRLP and LRHP conditions and these indirect effects are not moderated by condition. D) latent EXT effects on β are not mediated by latent working memory factors and these direct effects are moderated by condition. Multivariate kurtosis was .63, 3.27, −.51, .70 for models A–D, respectively.

Table 1

Measurement and Mediation Model Fit Statistics for Full Sample (N = 361)

Model description	χ^2	*df*	**p-value**	**NFI**	**RMSEA**	**LO 90**	**HI 90**	**BIC**
Measurement Models								
EXT with two-factor model (Figure 4a)	24.67	16	.076	.98	.04	.00	.11	142.46
EXT with common variance model (Figure 4b)	23.28	15	.078	.98	.04	.00	.11	146.98
Mediation Model:								
Conventional Go/No-Go measures by HRLP and LRHP								
Unmediated effects of EXT on pFA	4.43	4	.35	.99	.02	.00	.08	69.21
Mediated effects of EXT on pFA (Figure 5a)	40.67	26	.03	.97	.04	.01	.06	211.44
Unmediated effects of EXT on pHT	4.30	4	.37	.99	.01	.00	.08	69.08
Mediated effects of EXT on pHT (Figure 5b)	35.52	26	.10	.97	.03	.00	.06	206.29
Mediation Model:								
SDT Go/No-Go measures by HRLP and LRHP								
Unmediated effects of EXT on d'	8.48	4	.08	.99	.06	.00	.11	73.26
Mediated effects of EXT on d' (Figure 5c)	35.26	26	.11	.98	.03	.00	.06	206.04
Unmediated effects of EXT on log(β)	4.98	4	.29	.99	.03	.00	.09	69.76
Mediated effects of EXT on log(β) (Figure 5d)	33.84	26	.14	.97	.03	.00	.05	204.62

χ^2 = Chi-square; df = degrees of freedom; NFI = normed fit index; RMSEA = root mean square of approximation; LO 90 = lower boundary of RMSEA 90% confidence interval; HI 90 = upper boundary of RMSEA 90% confidence interval; BIC = Bayesian information criterion; EXT = Externalizing; Working Memory Capacity; pHT = hit rate; pFA = false alarm rate; d' = discriminability; log(β) = response bias

Table 2

Univariate Statistics and Bivariate Correlations among Indicators of Externalizing Psychopathology, Working Memory Capacity, and Go/No-Go Performance for Full Sample (N=361).

	Latent EXT			Latent EWMC		Latent STMC			Conventional Go/No-Go				SDT Go/No-Go			
Indicators	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Externalizing Problems																
1. ALC	~															
2. DRG	**0.67**	~														
3. AAB	**0.68**	**0.66**	~													
Executive Working Memory Capacity																
4. ACT	**−0.26**	**−0.34**	**−0.34**	~												
5. OWS	**−0.20**	**−0.28**	**−0.27**	**0.66**	~											
Short-term Memory Capacity																
6. DFS	−0.07	−0.10	−0.10	**0.35**	**0.38**	~										
7. DBS	**−0.18**	**−0.19**	**−0.17**	**0.48**	**0.42**	**0.57**	~									
8. LNS	**−0.15**	**−0.24**	**−0.23**	**0.45**	**0.44**	**0.49**	**0.59**	~								
Conventional Go/No-Go Measures																
9. HRLP - pFA	0.08	0.14	0.10	**−0.30**	**−0.32**	**−0.18**	**−0.18**	**−0.23**	~							
10. LRHP - pFA	**0.12**	**0.20**	**0.17**	**−0.26**	**−0.34**	**−0.23**	**−0.15**	**−0.17**	**0.50**	~						
11. HRLP - pHT	**−0.11**	**−0.18**	**−0.17**	**0.21**	**0.12**	**0.18**	**0.19**	**0.24**	0.04	0.02	~					
12. LRHP - pHT	−0.03	−0.06	−0.09	**0.13**	0.07	0.09	**0.17**	**0.20**	0.01	**0.26**	**0.29**	~				
SDT Go/No-Go Measures																
13. HRLP - d'	**−0.14**	**−0.23**	**−0.19**	**0.36**	**0.31**	**0.23**	**0.25**	**0.33**	**−0.76**	**−0.38**	**0.59**	**0.17**	~			
14. LRHP - d'	**−0.14**	**−0.24**	**−0.22**	**0.33**	**0.35**	**0.28**	**0.29**	**0.32**	**−0.41**	**−0.65**	**0.20**	**0.53**	**0.45**	~		
15. HRLP - log(β)	**0.12**	**0.19**	**0.20**	**−0.15**	−0.09	**−0.12**	**−0.14**	**−0.17**	−0.07	−0.03	**−0.79**	**−0.25**	**−0.53**	**−0.16**	~	
16. LRHP - log(β)	0.02	0.06	0.08	**−0.12**	−0.06	**−0.11**	**−0.22**	**−0.22**	−0.07	**−0.37**	**−0.22**	**−0.73**	−0.07	**−0.31**	**0.20**	~
Mean	0.00	0.05	0.01	28.08	41.40	9.57	8.39	12.06	0.40	0.35	0.83	0.76	1.34	1.25	−0.50	−0.22
Standard Deviation	0.97	0.88	1.00	11.69	11.67	2.00	2.31	2.56	0.21	0.20	0.12	0.16	0.78	0.70	0.62	0.60
Skewness	0.14	0.63	0.01	−0.26	−0.63	−0.23	0.29	0.35	0.58	0.71	−1.00	−1.16	0.07	0.09	−0.77	−0.58
Kurtosis	−0.32	−0.46	−0.14	−0.78	0.09	−0.28	−0.55	0.38	−0.51	−0.38	1.18	1.69	−0.38	−0.34	0.73	1.33

EXT = externalizing; EWMC = executive working memory capacity; STMC = short-term memory capacity; SDT = Signal Detection Theory; ALC = alcohol; DRG = illicit drug; AAB = adult antisocial behavior; ACT = auditory consonant trigram; OWS = operation word span; DF = digits forward; DB = digits backward; LNS = letter number sequencing; HRLP = high-reward/low-punishment; LRHP = low-reward/high-punishment; pFA = false alarm rate; pHT = hit rate; d' = discriminability; log(β) = response bias. Bolded correlation coefficients are significant at $p < .05$