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The Effects of a Working Memory Load on Delay Discounting in Those With Externalizing Psychopathology

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Abstract

This study investigated the influence of executive working memory (EWM) capacity on impulsive decision making in a sample of young adults ($N = 623$) who varied in degree of externalizing psychopathology (EXT) by examining (a) the effects of WM load on delay discounting rates and (b) the association between EWM capacity and delay discounting rates. EXT was measured as a latent variable indicated by lifetime problems with alcohol, marijuana, nicotine, other drugs, childhood conduct, and adult antisocial behavior. Results showed that (a) the WM load increased discounting rates throughout the spectrum of EXT, (b) EXT was associated with higher discounting rates and lower EWM capacity, and (c) EWM capacity was significantly associated with higher discounting rates when controlling for IQ, but only after a WM load. The results are discussed in terms of the role of EWM capacity in impulsive decision making in EXT.

Keywords
externalizing psychopathology, working memory capacity, delay discounting, impulsive decision making

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A central feature of externalizing psychopathology (EXT), including substance use disorders and antisocial psychopathology, is poor self-regulation characterized by impulsive decision making, such as increased discounting of delayed rewards and disadvantageous decision making, and reduced executive working memory (EWM) capacity (Baker, Johnson, & Bickel, 2003; Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Bechara & Martin, 2004; Bickel et al., 2007; Bobova, Finn, Rickert, & Lucas, 2009; Endres, Donkin, & Finn, 2014; Endres, Rickert, Bogg, Lucas, & Finn, 2011; Fridberg, Gerst, & Finn, 2013; Romer, Bentacourt, Gianetta, Brodsky, & Farah, 2009). Research suggests that EXT represents a spectrum of co-occurring disorders or symptoms that share a common disinhibitory vulnerability (Bobova et al., 2009; Endres et al., 2011; Endres et al., 2014; Krueger et al., 2002) associated with reduced EWM capacity and high levels of impulsive/sensation seeking personality traits (Bogg & Finn, 2010). Theory and research suggest that EWM capacity plays a central role in self-regulation and adaptive decision making (Barkley, 2001; Barrett, Tugade, & Engle, 2004; Endres et al., 2011; Endres et al., 2014; Finn, 2002) and shares part of the association between EXT and impaired decision making in associative learning approach–avoidance contexts (Endres et al., 2014; Endres et al., 2011). However, there are relatively few studies of the association among reduced EWM capacity, impulsive decision making, and EXT.

EWM Capacity, Decision Making, and EXT

Working memory has been described as a limited-capacity information processing system composed of interdependent processes related to the executive control of attention (the central executive) and the active maintenance of short-term memory (Baddeley & Logie, 1999; Cowan, Fristoe, Elliott, Brunner, & Saults, 2006; Engle, Tuholski,

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Laughlin, & Conway, 1999; Miyake & Shah, 1999; Shipstead, Redick, Hicks, & Engle, 2012). Research suggests that the capacity of the working memory system can be partitioned into separate capacities for the central executive (EWM capacity) and the scope of attention or short-term memory capacity (e.g., Cowan et al., 2006; Engle et al., 1999; Shipstead et al., 2012). We focus here on the capacity of the central executive component (i.e., EWM), which is common to all models of the working memory system (Barrett et al., 2004; Cowan et al., 2006; Miyake & Shah, 1999), because its function is most critical for the adaptive self-regulation and decision making (Barkley, 2001; Barrett et al., 2004; Finn, 2002; Oberauer, 2002) and the deliberative process during decision making in particular (Endres et al., 2014). EWM capacity is thought to reflect the ability to control attention associated with the capacity to direct and shift attention, and resist distraction, while encoding/updating, maintaining, and retrieving information from long- and short-term memory buffers (Barrett et al., 2004; Cowan et al., 2006; Shipstead et al., 2012), a process that we maintain is critical during the decision-making deliberation process (Endres et al., 2014; Finn, 2002). EWM capacity is typically assessed using complex span tasks that include a dual task component (Conway et al., 2005; Redick et al., 2012).

In our model of EWM capacity and decision making (Endres et al., 2014; Finn, 2002), this attention control process is inherent in the deliberation process involved in effective decision making (Finn, 2002). Optimal decision making between two or more alternatives involves greater EWM capacity, which reflects the capacity to shift attention between the different options, while keeping in mind short- and long-term goals, resisting distraction from decision-irrelevant information, and considering options by weighing costs and benefits and accessing long-term memory for experience, and short- and long-term goals and plans (Endres et al., 2014; Finn, 2002). In decision contexts aspects of a decision that have an immediate relevance have a higher salience than aspects of a decision that have a longer term relevance, and attention is likely to be drawn first to the higher salient option (Busemeyer & Townsend, 1993; Finn, 2002). In the context of delay discounting tasks, choices in favor of long-term larger rewards require keeping in mind the value of the immediate option, shifting attention away from this more salient option to the delayed option, then keeping in mind both options and deliberating about the decision, which may involve accessing long-term memory for long-term plans and goals. Thus, a greater EWM capacity should be associated with more long-term choices or, in the context of a delay discounting task, lower delay discounting rates.

A number of studies report that reduced EWM capacity is associated with impaired decision making on a variety of tasks, such as delay discounting (Bobova et al., 2009; Shamosh et al., 2008), the Iowa Gambling Task (Bechara & Martin, 2004; Fridberg et al., 2013; van der Plas, Crone, van den Wildenberg, Tranel, & Bechara, 2009), and incentivized approach–avoidance learning tasks (Endres et al., 2011; Endres et al., 2014). EXT also has been associated with reduced EWM capacity (Bogg & Finn, 2010; Endres et al., 2011; Endres et al., 2014; Finn et al., 2009; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) and impulsive decision making on delay discounting tasks (Barkley et al., 2001; Bickel et al., 2007; Bjork, Hommer, Grant, & Danube, 2004; Bobova et al., 2009; Kirby & Petry, 2004; Mitchell, Fields, D'Esposito, & Boettiger, 2005; Petry, 2002). Recent studies suggest that the disinhibited decision making on approach–avoidance learning tasks observed in those with high levels of EXT is associated with low EWM capacity (Endres et al., 2011; Endres et al., 2014). Further illustrating the role of EWM capacity in decision making are studies that show that a working memory (WM) load increases disadvantageous decision making on the Iowa Gambling Task (Fridberg et al., 2013; Hinson, Jameson, & Whitney, 2002) and impulsive decision making on approach–avoidance learning tasks (Endres et al., 2014). Some work also suggests that a WM load may increase delay discounting rates as well (Hinson, Jameson, & Whitney, 2003). However, a recent study failed to replicate this effect (Franco-Watkins, Rickard, & Pashler, 2010). The generalizability of these latter two studies is questionable because of their small samples of undergraduate students participating for course credit, and the use of a discounting task involving very large hypothetical sums of money that are not likely to represent real-life choices for this population.

The current study was designed to further investigate the association between EWM capacity and impulsive decision making in EXT by examining the effect of a WM load during a delay discounting task as well as by examining the interrelationships among measures of EWM capacity, delay discounting rates, and a dimensional latent variable measure of EXT with and without a WM load. The study tested the hypotheses (a) that WM load will result in greater increases in delay discounting rates in general, but that those high in EXT would experience greater increases in delay discounting rates, because externalizers have higher levels of impulsivity/disinhibitory tendencies (Bogg & Finn, 2010); (b) that EWM capacity would be associated with higher delay discounting rates in general, and the association between EWM capacity and discounting would be stronger in the WM load condition, because a high EWM capacity may offset to some degree that increases in discounting experienced under a WM load; and (c) that EWM capacity would share some of the variance in delay discounting associated with EXT, suggesting that at least part of

Table 1. Demographic Characteristics and Lifetime Problem Counts by Condition

Measure/variable	Full sample	WM load	No WM load
n (male/female)	623 (331/292)	314 (168/146)	309 (163/146)
Mean age	21.4 (2.6)	21.3 (2.5)	21.5 (2.6)
Mean years of education	14.0 (1.8)	14.0 (1.6)	14.0 (1.9)
Percentage current student	78.3	78.0	78.6
Mean ACT	30.1 (9.4)	30.0 (9.4)	30.2 (9.4)
Mean OWS	40.4 (10.0)	40.9 (9.9)	39.9 (10.1)
Mean EXT factor score	0.00 (1.0)	–0.01 (1.0)	0.01 (1.0)
Mean lifetime problems with			
Alcohol	17.5 (14.2)	17.5 (14.6)	17.5 (13.9)
Marijuana	7.0 (8.9)	6.9 (9.2)	7.1(8.8)
Nicotine	3.4 (5.3)	3.5 (5.3)	3.3 (5.3)
Other drug	7.3 (18.4)	7.1 (18.6)	7.4 (18.2)
Conduct disorder problems	8.2 (6.2)	8.3 (6.3)	8.1 (6.1)
Adult antisocial problems	7.0 (6.7)	6.9 (6.4)	7.1 (6.9)

Note: Values in parentheses are standard deviations, unless otherwise noted. ACT = Auditory Consonant Test; EXT = externalizing psychopathology; OWS = Operation Word Span test; WM = working memory.

the association between EXT and delay discounting is associated with reduced EWM capacity. Additional analyses of choice reaction times (RTs) were conducted to assess the effects of the WM load on decision time and test the hypothesis that EXT would be associated with faster choice RTs reflecting a less deliberative impulsive decision style.

Method

Participants

Sample characteristics. The sample consisted of 623 young adults (331 men, 292 women), with a range of EXT symptoms (alcohol problems, drug problems, nicotine dependence problems, antisocial behavior, conduct problems). The sample was 78.5% White, 7.2% African American, 5.8% Asian, Indian, or Middle Eastern, 5.3% Hispanic or Latino, and 0.6% Native American, with 2.2% endorsing multiple ethnicities. Of the total sample, 41% (*n* = 258) met criteria for lifetime alcohol dependence (AD), 31% (*n* = 194) for marijuana dependence, 16% (*n* = 98) for other drug dependence, 30% (*n* = 187) for conduct disorder (CD), and 16% (*n* = 97) for antisocial personality disorder. Diagnoses were ascertained with the Semi-Structured Assessment for the Genetics of Alcoholism (SSAGA; Bucholz, Cadoret, Cloninger, & Dinwiddie, 1994) using diagnostic criteria of the fourth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 1994). Sample characteristics are listed in Table 1.

Recruitment. Participants were recruited using advertisements placed in local and student newspapers and around the community. This approach has been effective in attracting responses from individuals who vary in EXT problems and disorders (Finn et al., 2009; Finn, Mazas, Justus, & Steinmetz, 2002). The range of ads/flyers targeted “daring, rebellious, defiant individuals,” “carefree, adventurous individuals who have led exciting and impulsive lives,” “impulsive individuals,” “heavy drinkers wanted for psychological research,” persons with a “drinking problem,” persons who “got into a lot of trouble as a child,” persons “interested in psychological research,” “quiet, reflective and introspective persons,” and “social drinkers.”

Advertisement respondents were screened via telephone to determine whether they met basic study inclusion criteria. The study inclusion criteria were age between 18 and 30, ability to read and speak English, at least a sixth grade education, consumption of alcohol on at least one occasion, and no history of psychosis or head trauma. If respondents met the basic inclusion criteria, they were asked a series of screening questions about current and lifetime alcohol, drug, childhood conduct, and adult antisocial problems. Subjects were invited to participate in the study if they fell within the range of these EXT problems that were targeted for the sample composition. We screened to target a sample composed of 25% with relatively low EXT problems (no diagnosable AD/abuse, marijuana/other drug dependence/abuse, no diagnosable CD, low adult antisocial behavior, no current binge drinking), 50% with moderate (moderate-low to moderate-high) levels of EXT problems, and 25% with very high levels of EXT problems (at least a lifetime diagnosis of AD and CD). We targeted these segments based on the distributions of these EXT problems that we had in our earlier studies that employed a dimensional model of EXT problems (Bogg & Finn, 2010; Finn et al., 2009). Lifetime alcohol, marijuana, nicotine, other drugs, childhood conduct, and adult antisocial problems counts were ascertained with the SSAGA. Table 1 lists the mean lifetime problems with alcohol, marijuana, nicotine, other drugs, conduct, and adult antisocial behavior for the full sample and for the subsamples in the WM load and no load conditions of the delay discounting task. As can be seen, the subsamples for the WM load condition are equivalent for all variables.

Test session exclusion criteria. To be tested, subjects had to meet specific criteria on the day of testing. These criteria were (a) no self-reported use of alcohol or drugs within the past 12 hr, (b) having had at least 6 hr of sleep the night before, (c) having a breath alcohol level of 0.0% (tested with a AlcoSensor IV, Intoximeters Inc., St. Louis, MO), and (d) not experiencing withdrawal symptoms or feeling ill. Subjects were rescheduled if they did not meet any of these criteria.

Assessment procedures and materials

EWM capacity. EWM was assessed using two different complex-span tests, the Operation Word Span (OWS) test (Conway & Engle, 1994) and a modified version of the Auditory Consonant Trigram test (Brown, 1958), which we refer to as the Auditory Consonant Test (ACT). Numerous studies indicate that such complex span tests reflect the EWM-related capacities to direct and shift attention, and resist distraction, while encoding/updating, maintaining, and retrieving information from long- and short-term memory buffers (Endres et al., 2011; Endres et al., 2014; Engle et al., 1999; Unsworth & Engle, 2007). The OWS test involves competition for attentional resources and the maintenance of activation of mental representations in a dual task context. The test requires solving a simple mathematical operation while remembering a word (6/3 + 2 = 4 DOG). The subject reads the math operation aloud, responds yes or no to indicate if the answer is correct or not, and then says the word; one half of the mathematical operations are correct. After a series of operation–word pairs (varying from 2 to 6), the subject is asked to recall the words in the exact order he or she was presented. Performance on this measure is quantified as the total number of correctly recalled words.

In its original form, the ACT test involves recalling three-consonant nonsense strings after counting backward for varying periods of time. This test presumably taps divided attention and the strength of the maintenance/decay of the contents of WM over time (Brown, 1958; Stuss, Stethem, & Poirier, 1987). To increase WM load, similar to Melton (1963), we modified the test by including four- and five-consonant nonsense strings in addition to the original three-consonant strings to make the task more demanding. Greater loads are expected to amplify group differences. In this test, the experimenter reads aloud a string of consonants at a rate of one letter per second, followed by a three-digit number. The subject counts backward by threes from that number for either 18 or 36 s and is asked then to recall the original consonant string. Counting backward is assumed to interfere with rehearsal of the original consonant string. For all string lengths, two were followed by 18-s delay intervals and two were followed by 36-s delay intervals. Performance on this test was quantified as the total number of correct consonants recalled across all string lengths and delay intervals.

As noted earlier, EWM capacity reflects multiple processes (Cowan et al., 2005), some which are shared between the OWS and ACT tests. However, each task taps other cognitive processes to differing degrees, such as those associated with the effects of distraction, memory maintenance and retrieval, and the degree of attention shifting. The multidimensional nature of these tasks can make it difficult to separate specific EWM processes with these tasks (Cowan et al., 2005). We use both tasks because our previous work indicates that they are highly correlated with correlation coefficients between .48 and .66 (Bogg & Finn, 2010; Endres et al., 2011; Endres et al., 2014; Finn et al., 2009) and predictive of key aspects of decision making, such as stimulus discrimination and evidence accumulation rates during deliberation (Endres et al., 2011; Endres et al., 2014). The correlation between these two measure in the current sample is $r = .49$, $p < .0001$. In the current article, the primary analyses treat these two measures as indicators of a latent EWM capacity variable, but we also present the analyses separately for each measure (OWS and ACT) in the Supplemental Materials available online to investigate whether one of the indicators may be carrying most of the effects observed in the structural equation model with the latent EWM capacity variable.

Delay discounting task. The delay discounting task was administered via computer. Participants were asked to choose between a specific amount of money "now" or $50 "later" at one of six time delays (i.e., 1 week, 2 weeks, 1 month, 3 months, 6 months, 1 year). The immediate amount varied from $2.50 to $47.50 in $2.50 increments. Prior to doing the task, participants had been told that they would obtain the amount they chose on one of the trials based on a random selection of one of the outcomes of one of the choice trials. If that random selection was a decision where they chose the immediate amount, they would receive that amount in cash right away. If that decision was a LATER decision, they would get a voucher for the $50.00 that could be redeemed after the period of time had elapsed (up to 1 year later). The task was run in six blocks, one for each delay (1 week, 2 weeks, 1 month, 3 months, 6 months, and 1 year). The blocks were presented randomly. Within each block there were ascending and descending value trials (the order of which was random). On the ascending trials, the immediate reward value increased from \$2.50 to a maximum of \$47.50 in \$2.50 increments. The ascending sequence stopped when they switched from the delayed to the immediate (or stopped at \$2.50 if they chose the immediate option right away), a total of 19 possible ascending trials for each time point. The point at which they switched from the delayed (\$50.00) to the immediate option was recorded as the switch point for the ascending trials. On descending trials the immediate values decreased from \$47.50 to \$2.50 in \$2.50 increments. The descending sequence of decision trials stopped when they switched from the immediate to the delayed option. The point at which they switched from the immediate to the delayed (\$50.00) option was recorded as the switch point for the descending sequence of decision trials.

WM load. Participants were randomly assigned to do the delay discounting task in either a "WM load" or a "no load" version of the task. These two versions were identical except for that in the WM load version of the task, a decision trial started with the choice between an amount of money NOW (e.g., \$47.50 NOW) and "\$50.00 LATER, then a number appeared on the screen (e.g., 457) and participants counted backward in threes from that number (e.g., 454, 451. . .) for 10 s; then "MONEY NOW MONEY LATER" was presented on the screen (no monetary values were provided) and participants were required to make a key press for their decision (the NOW or LATER option). After choosing the NOW or LATER option, participants were prompted to recall the number presented at the beginning of the trial. The no load version of the task included a 10-s wait period to reduce confounds that may be caused by rapid succession of decision trials or shorter overall completion of the task.

Thus, the WM load has two components, a memory maintenance component (keeping in mind the three-digit number) and an attention shifting component (shifting between the decision option and counting backward) specifically designed to deplete EWM capacity reserves. We assume that the WM load depletes EWM capacity by requiring the constant shifting of attention back and forth from the primary task of deciding between the NOW or LATER options to the secondary task of counting backward, which we also assume depletes attentional resources. These kinds of dual tasks are known to tax and deplete WM resources (e.g., Anguera et al., 2012). Participants appeared to have no problem following instructions for the load. There was an overall 85% accuracy in recalling the three-digit number, which was unassociated with EXT latent variable scores. For instance, looking at accuracy rates across the EXT latent variable divided by tertiles, high EXT had a rate of 82%, moderate EXT had a rate of 81%, and low EXT had a rate of 83%. Participants received eight practice trials in the load and no load conditions.

Estimation of discounting rate. A single-parameter hyperbolic function was used to estimate discounting rate (Mazur, 1987). The following equation represents that estimation: $V_p = V/(1 + k \times dt)$, where V_p was the present (discounted) value (the average of the switch point for ascending and descending trials at a particular delay), the constant V was the amount of the delayed reward (\$50), dt was the length of the time the reward is delayed in days, and k was the discounting rate. The dependent variable used in these analyses is the $\log_{10}$ transformed k value. This hyperbolic model has been found to account for significantly more variance than exponential function models in several studies using real rewards in humans (Bickel & Marsch, 2001; Kirby, 1997; Kirby & Herrnstein, 1995). This hyperbolic function suggests that when the larger reward in question is more temporally distant, choices for those rewards can be described as more controlled, rational, and consistent with long-term goals. Conversely, when smaller sooner rewards are available, these choices can be described as impulsive and inconsistent with long-term goals. Following the guidelines of Johnson and Bickel (2008), six participants were excluded from the analyses because their choices were variable and unsystematic, exhibiting increases in the magnitude of switch points (starting at the second delay) by a magnitude greater than 20% of the larger reward. An additional 75 participants were excluded because they met Johnson and Bickel's second criterion of not discounting by at least 10% from the first to the last delay. There were 54 participants, who never discounted and always chose the \$50 delayed reward (33 in the no WM load and 21 in the WM load condition). There were 21 participants who always chose the immediate reward (5 in the no WM load and 16 in the WM load condition). These participants were excluded because the hyperbolic function cannot adequately estimate k because their choices do not have a rate of decline. However, the Section S1 in the Supplemental Material presents the main analyses that include these subjects because the choices by these 75 participants seemed valid given the context of our task that involved real versus hypothetical rewards, spread over a relatively short span of delays.

Data analyses

All analyses used the final sample of 542 participants after dropping out the 75 participants who violated the criteria outlined by Johnson and Bickel (2008).

Multiple regression was used to examine the main effects of the EXT factor and WM load and the interaction between WM load and EXT to test the hypotheses regarding the effect of the WM load manipulation on discounting rate ($\log_{10}$ transformed *k* value), as well as whether WM load moderated the association between EXT and discounting rate (the EXT by WM load interaction effect). SPSS Version 19.0 (SPSS Inc., Chicago, IL) was used for this analysis. An EXT factor score was computed using maximum likelihood factor analysis of Blom-transformed EXT problem counts (alcohol, marijuana, nicotine, other drug, conduct, and adult antisocial behavior problem counts). Blom transforms were used in an attempt to address the problem of nonnormally distributed problem counts as suggested by van den Oord and colleagues (2000) and employed by Krueger and colleagues (2002). However, Blom transformation does not completely normalize the substance use symptom counts because these are zero inflated. The maximum likelihood factor analysis yielded one factor (eigenvalue = 3.871) accounting for 64.5% of the variance in the problem counts. A tertile split of the EXT factor score was also computed to visually illustrate differences in discounting rates means across low, medium, and high EXT groups by WM load.

Additional follow-up analyses. Because monetary choices in our delay discounting task can be affected by socioeconomic status (SES) in terms of immediate need for money, an additional follow-up analysis was conducted that covaried the effects of SES in combination with the EXT factor (see Section S2 in the Supplemental Material). We used years of education as a proxy for SES because it is highly correlated with SES and we did not have a specific measure of SES.

Structural equation modeling (SEM) through Amos Version 21 (Arbuckle, 2012) was used to assess the interrelationships among the EXT factor, the EWM capacity factor, and delay discounting rate ($\log_{10}(k)$). In addition, a multiple-group SEM (no load vs. WM load) was used to test the hypothesis that the path from EWM capacity to $\log_{10}(k)$ would be stronger in the WM load compared with no load condition. The multiple-group SEM was conducted in three stages. First, the measurement invariance for the factor loadings for the indicators for the two latent variables (EXT and the EWM capacity) across no load and WM load conditions was tested by comparing an unconstrained model with a model that constrained these factor loads to be equal. Second, the invariance in factor loadings and residuals was assessed comparing an unconstrained model with a model constraining these parameters to be equal across no load and WM load conditions. Finally, differences between load conditions in the path from EWM capacity to $\log_{10}(k)$ were assessed comparing the fit of a fully constrained model with the fit of a model that was fully constrained with the exception of the path from EWM capacity to $\log_{10}(k)$. The structural equation models used bootstrapped (k = 20,000), and bias-corrected 95% confidence intervals (CIs; Preacher, Rucker, & Hayes, 2007) around the indirect effects (of EXT on $\log_{10}(k)$ via EWM capacity) were calculated to assess whether EWM capacity and EXT shared any of the variance in delay discounting rate in the WM load and no load conditions. Goodness of fit was assessed with the χ^2 goodness of fit, the normed fit index (NFI; Bentler & Bonett, 1980), the comparative fit index (CFI; Bentler, 1990), and the root mean square error of approximation (RMSEA; Browne & Cudeck, 1993). Typically, NFI and CFI values above .90 or .95 and RMSEA values at or below .05 reflect a good fit to the data (Bentler & Bonett, 1980; Browne & Cudeck, 1993; Hu & Bentler, 1999).

Additional follow-up analyses. Additional structural equation models were conducted with each individual indicator of EWM capacity (OWS and ACT) to assess whether the results mirror the results with the EWM capacity latent variable and determine whether one or the other indicator is carrying the overall effects. These are reported in Sections S3 and S4 of the Supplemental Material. Finally, because the association between reduced EWM capacity and increased delay discounting may be due to a more generalized reduction in cognitive capacity rather than to any process specific to EWM capacity, IQ was added to the SEM (EXT, EWM capacity, and delay discounting) as an endogenous intermediate variable covaried with EWM capacity to assess whether IQ accounted for any of the association between EWM capacity and discounting rate. This analysis is reported in Section S5 of the Supplemental Material. IQ was measured with the Wechsler Abbreviated Scale of Intelligence (Psychological Corporation, 1999).

Choice RT. The main effects of WM load and EXT and their interaction on overall choice RT (averaged across all decisions) were analyzed using multiple regression. Choice RT for the switch points at each delay on both the descending (switch choice from immediate to $50 delay) and the ascending (switch choice from the $50 delayed to the immediate amount) was analyzed using repeated measures ANOVA (EXT grouped into high, moderate, low).

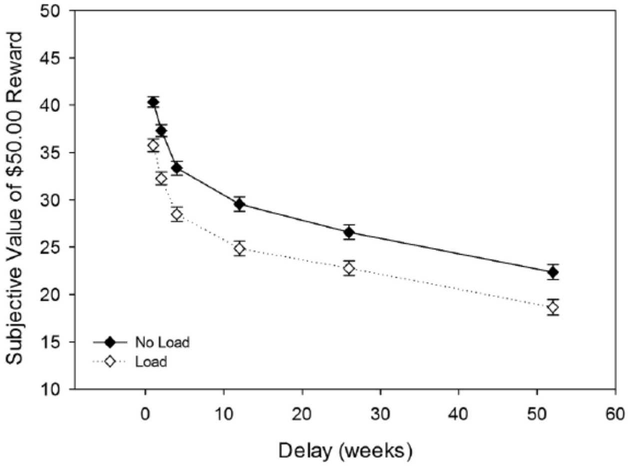

Fig. 1. Log-transformed estimation of discounting curves for load and no load conditions with standard errors for predicted values.

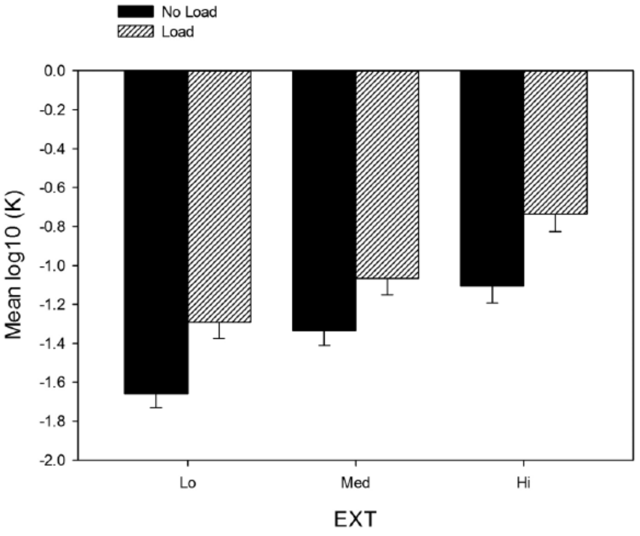

Fig. 2. Mean $\log_{10}(k)$ by tertile-split groups of externalizing psychopathology in the load and no load conditions. Error bars represent the standard errors of the mean.

Results

WM load, EXT and delay discounting rate

The multiple regression analyses revealed significant main effects of WM load, $F(1, 538) = 26.3$, $\beta = .20$, $p < .0001$, and EXT psychopathology, $F(1, 538) = 30.0$, $\beta = .31$, $p < .0001$, on delay discounting rate, $\log_{10}(k)$. As hypothesized, the WM load was associated with significantly higher discounting rates, WM load: $M = -1.03$, $SD = 0.85$ versus no load: $M = -1.36$, $SD = 0.79$, $t(538) = -4.57$, $p < .001$, $d = 0.40$, and EXT also was associated with higher discounting rates. The interaction between WM load and EXT was not significant, $F(1, 538) = 0.21$, $\beta = .03$, indicating that there were no differences in the impact of the WM load on delay discounting for those with high levels of EXT (as hypothesized). These results were identical for the sample that included the 75 participants who had been dropped from the analyses (Section S1a of the Supplemental Material). Additional analyses indicated no significant main effect of sex, $F(1, 538) = 0.18$, *ns*, or interactions involving sex, Fs = 0.44, 1.14, 1.43. Figure 1 illustrates the effect of WM load on the hyperbolic discounting curves. Figure 2 displays the mean discounting rates in the WM load and no load conditions for the tertile-split groups (high, moderate, and low EXT groups). Figure 2 clearly illustrates the two separate main effects of WM load and EXT. Delay discounting rates ($\log_{10}(k)$) were significantly correlated with all indicators of the EXT latent variable: problems with alcohol ($r = .26$, $p < .0001$), marijuana ($r = .26$, $p < .0001$), other drugs ($r = .29$, $p < .0001$), childhood conduct ($r = .29$, $p < .0001$), and adult antisocial behavior ($r = .27$, $p < .0001$). Section S2 in the Supplemental Material illustrates that years of education was not significantly associated with delay discounting rate.

EXT and delay discounting: structural model analysis

The multiple-group SEM analysis demonstrated measurement invariance for the factor loadings for the EXT and EWM capacity latent variables across the no load and load conditions, difference $\chi^2(6) = 11.62$, $p = .07$. There also was invariance across conditions in the combination of measurement loadings and factor residuals, $\chi^2(8) = 12.5$, $p = .13$. The multiple-group model comparisons used to assess significant differences in the path from EWM capacity to the discounting rate parameter, $\log_{10}(k)$, between the no load and the load conditions also were nonsignificant, $\chi^2(1) = 3.03$, $p = .082$.

The SEM with the total sample fit the data adequately, $\chi^2(16) = 24.7$, $p = .08$; CFI = .99, NFI = .99, RMSEA = .03. Figure 3 illustrates the paths among EXT, EWM capacity, and the discounting parameter, $\log_{10}(k)$. EXT was significantly associated with higher discounting rates, ß = .31, $p < .0001$, and lower EWM capacity ß = –.28, $p < .0001$. EWM capacity also was significantly associated with lower discounting rates, ß = –.17, $p < .005$. There also was a significant indirect effect of EXT on discounting rate, $\beta = .05$, $p < .005$, 95% CI [.013, .09], indicating that EWM capacity shared part of the variance in discounting rate with EXT.

As illustrated in the Supplemental Material (Sections S3 and S4), these effects were mirrored in the separate structural equation models using OWS and ACT as

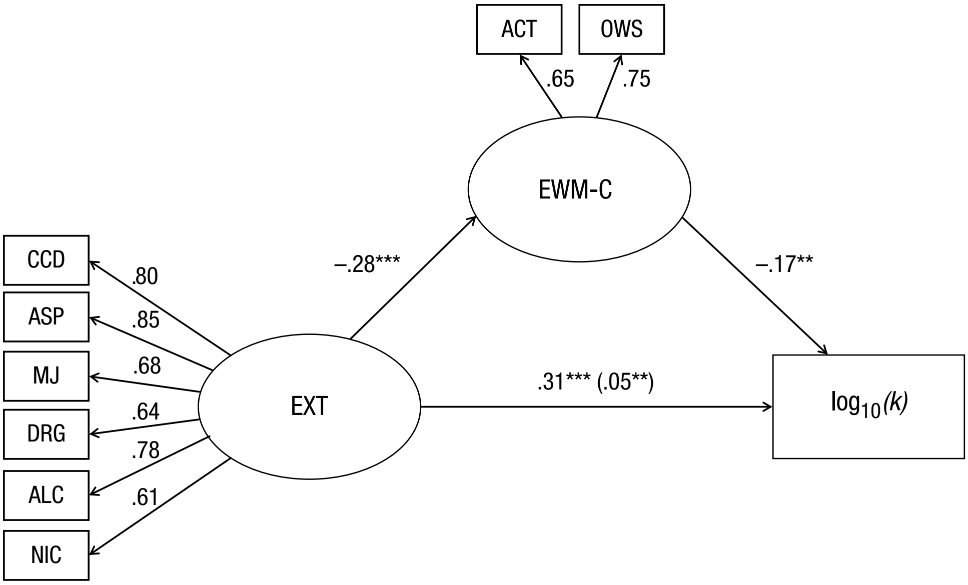

Fig. 3. Structural equation model (SEM) of the association among latent externalizing psychopathology (EXT) factor, executive working memory capacity (EWM-C), and delay discounting rate parameter, $\log_{10}(k)$. Path weight in inside parentheses indicate the indirect effect of EXT on $\log_{10}(k)$, which reflects the amount of the association between EWM-C and $\log_{10}(k)$ that is shared with EXT. All path weights are significant at $p < .001$, with the exception of $p < .01$ for those with two asterisks. ACT = Auditory Consonant Trigram performance; ALC = lifetime alcohol problems; ASP = lifetime antisocial behavior problems; CCD = lifetime childhood conduct problems; DRG = lifetime problems with other drugs; MJ = lifetime problems with marijuana; OWS = Operation Word Span performance.

separate measures of EWM capacity in both the no load and WM load conditions. Furthermore, when IQ was added to the model (supplemental analyses reported and illustrated in Section S5 of the Supplemental Material), the results remained the same.

A post hoc analysis modeling the path from the EXT latent variable to $\log_{10}(k)$ was conducted to address the question of whether any of the individual EXT psychopathology indicators were associated with $\log_{10}(k)$ beyond its covariance with other indicator measures (i.e., the EXT latent variable). This model fit the data very well, $\chi^2(14) = 7.59$, $p = .37$; NFI = .99, RMSEA = .012, Bayesian information criterion (BIC) = 97.63. Examination of the modification indices indicated that adding paths from any indicator to $\log_{10}(k)$ would not improve the fit of the model at all. A model specification search also was conducted using zero-based BIC_0 to guide model respecification. This also revealed that adding a path from any of the EXT psychopathology indicators would not improve model fit.

Choice RT. The multiple regression revealed that WM load significantly slowed overall choice RT from 1,686.8 ± 473.9 ms in the no load condition to 2,819.4 ± 910.5 ms in the WM load condition, $t(537) = 18.1$, $p < .0001$. EXT was significantly associated with slower overall choice RTs in the no WM load condition ($r = .25$, $p < .0001$) but not in the WM load condition ($r = .02$, *ns*). The ANOVA of the choice RTs at switch points also indicated that the WM load significantly slowed RTs, $F(1, 537) = 259.1$, $p < .0001$. In addition, EXT was associated with slower RTs in the no WM load condition (1432.7 ± 369.1, 1723.6 ± 635.7, and 1480.8 ± 665.1 for low, moderate, and high EXT groups). There also was a main effect of switch choice type, $F(1, 537) = 4.3$, $p < .05$, revealing that choice RTs when switching from the immediate to the delay $50 were faster than switching from the delayed $50 to the immediate amount (2,253.6 ± 1,227 ms vs. 2,344.6 ± 1,259). Delay discounting rate ($\log_{10}(k)$) was modestly associated with choice RT in the no load condition ($r = .15$, $p < .05$) but not the WM load condition ($r = .005$).

Discussion

The overarching goal of this study was to further our understanding of the role of EWM capacity in impulsive decision making in EXT by investigating (a) the impact of depleting EWM capacity on delay discounting and (b) the interrelationships among measures of EWM capacity, delay discounting rates, and a dimensional latent variable measure of EXT with and without a WM load.

There were four important results. First, a WM load significantly increased delay discounting rates for all subjects throughout the range of EXT. Notable about this result is the extremely high discounting rates under WM load in those with the highest levels of EXT psychopathology. Second, reduced EWM capacity was associated with higher delay discounting rates. EWM capacity shared a modest part of the variance in delay discounting with EXT, suggesting that the high rates of delay discounting observed in those with EXT may be partly due to reduced EWM capacity. Third, contrary to expectations, EXT psychopathology was associated with slower RTs in the no WM load condition. We recently reported a similar result where alcohol-dependent women had slower choice RTs when making risky decisions about drinking (Arcurio, Finn, & James, 2013). This suggests that although EXT psychopathology is associated with impulsive choices in terms of delay discounting rates, it is not associated with impulsivity in terms of making overly rapid or snap decisions. Although this is speculative, it may be that the faster decision times for those low in EXT in the no load condition were associated with more efficient deliberation about their decision during the 10-s wait period. In addition, the WM load was associated with slower overall choice RTs, also suggesting that the load did not increase snap decisions. Finally, similar to our earlier study (Bobova et al., 2009), EXT was significantly associated with higher delay discounting rates and none of the individual indicators of the EXT latent variable was associated with delay discounting beyond their covariance with one another. This suggests that increased delay discounting rates represent a common underlying characteristic of EXT psychopathology in general. Consistent with other reports, high delay discounting rates were significantly associated with each domain of EXT (Bickel et al., 2007; Bjork et al., 2004; Coffey, Gudleski, Saladin, & Brady, 2003; Heil, Johnson, Higgins, & Bickel, 2006; Kirby & Petry, 2004; Kirby, Petry, & Bickel, 1999; Mitchell et al., 2005; Petry, 2001, 2002). As in Bobova et al. (2009), we observed a univariate association between marijuana problems and higher delay discounting rates. This seems, on the face of it, to be contrary to the results of Johnson et al. (2010), who reported no differences in delay discounting rates between a marijuana-dependent group and a control group. However, in contrast to our study, Johnson et al. excluded all those with comorbid other drug abuse or dependence, whereas marijuana problems in our sample covaried with alcohol, other drug, childhood conduct, and adult antisocial problems.

The most significant finding in this study is that a WM load, designed to deplete EWM capacity, substantially increased delay discounting rates for all subjects. The current study extends the work of Hinson et al. (2003) by examining the effect of a WM load on a sample that varied widely in EXT. Although the discounting rates in those with high EXT did not increase to a greater degree than those low in EXT as we hypothesized, the increase in discounting rate across the range of EXT was dramatic. As illustrated in Figure 2, the WM load increased delay discounting rates in those with low EXT to a level equivalent to those with moderate EXT in the no load condition. Likewise, after a WM load, those with moderate EXT looked like those with high EXT without the load and those with high EXT had extremely high discounting rates under WM load. Other recent studies by our group also have reported that a WM load designed to compromise EWM capacity similarly increases disadvantageous decision making (Fridberg et al., 2013) and disinhibits decision making on an incentivized go/no go learning tasks (Endres et al., 2014) in those with high levels of EXT. Together, these results suggest that those with high EXT, who already have elevated discounting rates and patterns of disinhibited decision making, are very vulnerable to the effects of conditions that compromise WM capacity, such as stress, emotional arousal, and high cognitive load (Klein & Boals, 2001; Luehti, Meier, & Sandi, 2009; Xuebing, Xinying, & Lou, 2006). Under such conditions, those with very elevated EXT may be more likely to engage in impulsive/risky decisions that have significant negative consequences. Of interest, although we show that depleting EWM capacity increases delay discounting rates, a recent report suggests that boosting WM capacity via WM training can decrease delay discounting rates (Bickel, Yi, Landes, Hill, & Baxter, 2011). The results of Bickel et al. (2011) and the current study suggest that manipulating EWM capacity affects impulsive decision making, which provides a strong case for the key role that EWM capacity has in impulsive decision making and impulsivity in general (Bogg & Finn, 2010; Finn, 2002; Gunn & Finn, 2013; Romer et al., 2009).

In addition, the fact that EWM capacity was significantly associated with delay discounting rates after controlling for IQ further illustrates the important role that EWM capacity plays in delay discounting. This result is consistent with other reports associating reduced WM capacity with higher delay discounting rates (Bobova et al., 2009; Shamosh et al., 2008), less advantageous decisions on the Iowa Gambling Task (van der Plas et al., 2009), increased false alarms on a go/no go incentive learning task (Endres et al., 2011; Endres et al., 2014), and faster evidence accumulation rates for incorrect decisions on a go/no go incentive learning task (Endres et al., 2014).

Limitations and Conclusion

This study is not without limitations. First, our sample is mostly composed of young adult White college students and biased toward those interested in participating in research studies. Participants were not randomly selected and thus may not be representative of the distribution and severity of EXT psychopathology in the general population. Second, our data are cross-sectional by design, and the regression paths in the structural equation models cannot be interpreted as causal pathways. Although EXT may lead to high delay discounting rates and lower EWM capacity, both high discounting rates and low EWM capacity may contribute to the development of EXT. The SEM is structured as depicted in Figure 3 only so that we can assess the degree to which the association between EXT and delay discounting is shared by EWM capacity. Third, our measures of EWM capacity tap numerous EWM and related processes, some common to each task and some unique (Cowan et al., 2005), making it difficult to draw conclusions about exactly which processes may be related to delay discounting. The fact that we observed essentially the same relationships between the separate measures of EWM capacity and delay discounting (and EXT) increases confidence that each is tapping a common process that is important in decision making on delay discounting tasks; however, it remains to be demonstrated exactly which EWM processes are being engaged by these tasks that are relevant for delay discounting. Fourth, the EWM capacity latent variable is a weaker and perhaps less reliable index of EWM capacity because it is indicated by only two variables. Ideally, latent variables should be indicated by at least three variables.

Fifth, the use of real monetary rewards in the delay discounting task added an additional burden of having to redeem a voucher to receive the cash at the delayed date. This extra requirement may result in increased discounting of the delay reward in this task. In addition, the increased discounting rates observed in those with EXT psychopathology may have been partly due to different strategies or optimal behaviors based on life circumstances rather than impulsivity per se. It may be more optimal for those with high EXT to choose the immediate value more often because they may not know where they will be in the future and may be less able to redeem the delay reward voucher. Sixth, the WM load may have affected participants differently, and it is impossible from our data to precisely ascertain the exact nature of the impact of the WM load. For instance, the load might have led some to make snap decisions or to forget the choice options. Although the increase in choice RT after the load and the lack of an association between choice RT and discounting rate suggest that snap decisions were not driving load-related increases in delay discounting, we have no data to assess the degree to which forgetting may play a role in the WM load effects. However, it seems unlikely that forgetting played a major role in the outcome because forgetting would likely be random and would result in more erratic switch points that would have resulted in such data being excluded based on the Johnson and Bickel (2008) criteria. Also, the task structure of using ascending/descending sequences of immediate reward values, rather than a random presentation of choice decisions, may have mitigated forgetting because previous trial choice values are cues for the current values.

Finally, although the differences between the WM load and no load conditions in discounting rates are profound, ideally the optimal design to ascertain causal effects would be a within-subjects, pre–post design of the effects of a WM load on delay discounting. We did not use this design because of concerns regarding the possibility of practice or memory effects between two occasions of engaging in a delay discounting task. However, a within-subjects design would allow for the assessment of individual difference predictors of the effects of WM load on delay discounting and other relevant measures, if appropriate controls for experience with the task could be employed.

Aside from these limitations, this study makes three important contributions to the literature on the association among EXT behavior, EWM capacity, and impulsive decision making. First, the results clearly show that a cognitive load increases delay discounting rates. This result also indicates that the load was associated with very high discounting rates in those with high levels of EXT, suggesting that these individuals are quite vulnerable to extremes in impulsive decision making in situations that compromise WM capacity, such as stress, emotional arousal, or highly distracting contexts. Second, the results reveal that reduced EWM capacity is associated with increased delayed discounting, when under a cognitive load. The results also suggest the association between EXT and increased delay discounting is shared in part with reduced EWM capacity. On the other hand, the results indicate that much of the association between EXT and delay discounting is unrelated with EWM capacity, perhaps involving other processes such a greater preference for immediate rewards, an increased focus on immediate circumstances, and difficulties delaying gratification. Finally, the results provide further evidence for an association between EXT psychopathology and impulsive decision making assessed via a delay discounting task. The results suggest that this kind of pattern of impulsive decision making, whereby larger future rewards are discounted in favor of smaller immediate rewards, is a vulnerability shared by a range of EXT disorders and is not unique to any one domain of EXT psychopathology.

The results of this study also point to a few next steps that might further our knowledge of the relationships among impulsive decision making/delay discounting, WM capacity, and EXT. First, the nature of the effects of a WM load on delay discounting should be investigated further by comparing different types of WM loads on delay discounting choices. Different WM load manipulations can place different cognitive demands on participants, can elicit different compensatory strategies, and may have different impacts on performance, such as increasing forgetting or general fatigue. Second, a more thorough and systematic assessment of the role of different strategies used in task completion would help tease apart the different factors that affect discounting rates/impulsive decision making in those with EXT. Third, a more thorough assessment of different aspects of the WM system, such as basic attention capacity, mental manipulation, and EWM capacity, as well as other domains of executive cognitive function would help clarify which domains of WM processes and executive function are associated with delay discounting.

Author Contributions

P. R. Finn designed the study, conducted the majority of the analyses, and wrote the introduction results, and discussion of the final manuscript. R. L. Gunn conducted some analyses and aided Finn on all analyses, wrote the methods, and helped conceptualize the focus of the manuscript. K. R. Gerst managed all of the data, contributed to manuscript editing, and oversaw the conduct of the study.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://cpx.sagepub.com/content/by/supplemental-data.

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