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Working memory as a moderator of impulsivity and alcohol involvement: Testing the cognitive-motivational theory of alcohol use with prospective and working memory updating data

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HIGHLIGHTS

- Digit span moderated the relationship between social deviance and alcohol outcomes.
- The moderation effect persisted up to three years prospectively.
- This moderation effect was not found with measures of working memory updating.

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ABSTRACT

Research consistently shows that individuals high in impulsivity are at increased risk for excessive alcohol use and alcohol-related problems including alcohol use disorders (AUDs). Recent theorizing posits that working memory (WM) ability might moderate this association, but extant studies have suffered from methodological shortcomings, particularly mischaracterizing WM as a single, unitary construct and using only cross-sectional designs. This paper reports two studies that attempted to replicate and extend previous investigations of the relationship between WM, impulsivity, and alcohol involvement using two independent samples. Study 1 used a large ($N = 489$ at baseline), prospective cohort of college students at high and low risk for AUD to investigate interactions between WM capacity and impulsivity on cross-sectional and prospective alcohol involvement. Study 2 used a large ($N = 420$), cross-sectional sample of participants in an alcohol challenge study to investigate similar interactions between WM updating and impulsivity on recent alcohol involvement. Whereas Study 1 found that WM capacity moderates the relationship between some measures of impulsivity and alcohol involvement, with effects prospectively predicting alcohol involvement for up to three years, Study 2 did not find similar moderation effects when using measures of WM updating. These findings highlight the multifaceted nature of WM, which is often overlooked in the alcohol and impulsivity literature.

1. Introduction

Impulsivity is perhaps the most widely studied personality trait in the alcohol and addiction literature, demonstrating robust associations with alcohol use (e.g., Littlefield, Vergés, Wood, & Sher, 2012; Smith et al., 2007) and alcohol use disorder (AUD; e.g., Sher, Bartholow, & Wood, 2000). Recent theoretical and empirical work suggests that associations between impulsivity and alcohol involvement may be moderated by working memory (WM; Finn, 2002; Finn & Hall, 2004). Specifically, associations between impulsivity and alcohol involvement may be strongest in individuals with poorer WM capacity, resulting in poorer decision making and more problematic use.

Although this seminal work has provided a better understanding of the relationship between impulsivity, cognitive functioning, and alcohol involvement, these studies have primarily relied on cross-sectional data and measures of WM capacity (e.g., digit-span recall). Existing research suggests that WM is a multifaceted construct, however, of which capacity is one component process (Ecker, Lewandowsky, Oberauer, & Chee, 2010). Thus, studies ostensibly measuring "working memory" using capacity-based tasks may not capture the diversity of the WM construct. The current study addresses these gaps in the literature by testing the moderation effect of WM on associations between impulsivity and alcohol involvement in two independent samples, a longitudinal sample of first-time freshman college students (spanning late adolescence, early- and middle-adulthood) who completed tasks measuring WM capacity at baseline, and a sample of young adults participating in an alcohol challenge study who completed a battery of cognitive assessments,

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including multiple task measures of WM updating prior to participating in an experimental session.

1.1. Impulsivity and alcohol use

Broadly defined, impulsivity is the tendency to engage in behavior prematurely or without appropriate planning (Evenden, 1999). Although often discussed as a single, unitary construct, factor analytic evidence suggests that impulsivity is a heterogeneous construct with multiple facets (Cyders, Flory, Rainer, & Smith, 2009; Whiteside & Lynam, 2001; Zuckerman, 1994). In the current study, we primarily consider two facets of impulsivity: lack of planning, defined as the tendency to engage in a behavior before thinking about its consequences; and sensation seeking, defined as a tendency to seek out novel and rewarding sensations and experiences (Whiteside & Lynam, 2001; Zuckerman, 1994). Cross-sectionally, these facets are consistently associated with alcohol use ($r = .20$–$.27$) and alcohol-related problems ($r = .21$–$.29$) (Magid, MacLean, & Colder, 2007). Prospective studies have demonstrated correlated change between sensation seeking ($r = .15$) and lack of planning ($r = .28$–$.42$) with alcohol involvement (Littlefield, Sher, & Wood, 2009; Littlefield et al., 2012; Quinn & Harden, 2013).

1.2. Working memory

Working memory is generally defined as a limited-capacity mechanism (or set of mechanisms) that temporarily maintains and stores information for possible further cognitive processing (e.g., Ecker et al., 2010), with some conceptualizing WM as an interface between perception (e.g., characteristics of stimuli), long-term memory (e.g., knowledge about stimuli/contexts), and action (e.g., how to respond to stimuli; Baddeley, 2003). A major implication of this definition of WM relevant to cognition is that its contents must be continuously updated and dynamically integrated with long-term memory for the most effective action to be taken in response to a stimulus. Given this conceptualization, WM is widely considered a critical component of decision making. Despite a broad understanding of the importance of WM, soundly characterizing the effects of individual differences in WM on decision making (and other outcomes) is made difficult by the emerging understanding of WM as a complex, multifaceted process, coupled with a tendency among many researchers to treat all "working memory" tasks as indicators of the same underlying construct (e.g., Ecker et al., 2010; Kessler & Meiran, 2008; Oberauer & Kliegl, 2001). Relevant to this point, Kessler and Meiran (2008) argued that WM cannot itself be a unitary construct due to the paradoxical notion that, by definition, WM must at once be both *stable* (i.e., protected against irrelevant or outdated information) and *flexible* (i.e., rapid, dynamic modification of memory content when appropriate) in order to effectively operate. While the notion of multifaceted WM has been reflected in the literature through distinctions between WM *capacity* ability (i.e., stability) and WM *updating* ability (i.e., flexibility), there is disagreement regarding the relationship between these components of WM (e.g., Radvansky & Copeland, 2001; Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009).

To more adequately address this issue, Ecker et al. (2010) used a structural equation modeling approach to decompose performance on several commonly used WM updating tasks into the three hypothesized WM updating component processes of retrieval, transformation, and substitution. In addition, Ecker et al. (2010) also tested how these component processes relate to WM capacity individually and together. Results showed that, while WM capacity was significantly associated with the latent WM updating variable, the constituent processes of WM updating (i.e., retrieval, transformation, substitution) were uniquely and differentially associated with WM capacity, providing substantive evidence that WM updating and WM capacity represent related but distinct processes. These findings are consistent with neuroimaging work showing that WM updating and WM capacity are subserved by distinct neural regions (e.g., E. E. Smith & Jonides, 1997). Thus, considerable empirical and theoretical work indicates that characterizing WM as a single, unitary construct, defined in terms of either capacity or updating, is limited and fails to fully resolve the construct as currently defined.

1.3. Working memory and alcohol use

Empirical work has demonstrated robust associations between alcohol use and AUD with deficits in general executive functioning (EF; Bechara et al., 2001; Nigg et al., 2004; Tapert & Brown, 2000), as well as behavioral and fMRI measures of WM (Ambrose, Bowden, & Whelan, 2001; Harden & Pihl, 1995; Lovallo, Yechiam, Sorocco, Vincent, & Collins, 2006; Noël et al., 2001). Barkley (1997) posited that EF (including WM) mediates the relationship between disinhibition (e.g., acting without forethought) and externalizing behavior (e.g., seeking/consuming alcohol to experience its intoxicating effects). Indeed, WM is associated with risk factors related to disinhibition and addictive behavior, such as delay discounting (Bobova, Finn, Rickert, & Lucas, 2009), leading some to posit that the value placed on future events may be increased (or the devaluation of the future may be ameliorated) by increasing the ability to recall past events and/or future consequences (e.g., previous or potential instances of problematic substance use) (Bickel, Yi, Landes, Hill, & Baxter, 2011). Individuals prone to developing addictive behaviors, therefore, may have WM deficits that are specific to maintenance of information about long-term drinking consequences (Bechara, Damasio, Tranel, & Anderson, 1998) and/or general deficits in maintaining all types of information.

1.4. Working memory, impulsivity, and alcohol use

Several prominent models have posited that components of EF (e.g., WM and attention) interact with individual differences (e.g., impulsivity) to influence behavioral and emotional regulation, wherein dysregulation increases liability for engaging in externalizing behavior (Barkley, 1997; Eisenberg et al., 2000; Rothbart, Derryberry, & Posner, 1994). Applying this work to alcohol involvement, Finn (2002) proposed a cognitive-motivational theory of AUD in which EF moderates personality risk factors for alcohol use and problems. Empirical work has yielded some support for this theory, with digit-span recall moderating the relationship between a domain-specific measure of impulsivity, trait social deviance, and alcohol problems (Finn & Hall, 2004). These findings suggest that WM may moderate vulnerability to AUD through top-down control processes, particularly in individuals with general sensitivity to immediate rewards and/or specific sensitivity to alcohol's pharmacological effects.

1.5. The current study

The current investigation aimed to extend theoretical and empirical work on the interaction between WM and impulsivity, as posited by the cognitive-motivational theory of personality vulnerability to alcoholism (Finn, 2002), using two independent samples, each with unique strengths. The overarching goal of these studies was to characterize these impulsivity–working memory interactions prospectively and within the context of more recent conceptualizations of WM updating (e.g., Miyake & Friedman, 2012), as well as specific measures of impulsivity previously investigated in the literature, such as trait social deviance. First, we used a longitudinal sample spanning late adolescence and middle-adulthood (age 18–35) to investigate whether WM and impulsivity interact to prospectively predict alcohol involvement. If WM and impulsivity interact to predict future alcohol involvement (with stronger WM dampening the effect of impulsivity), this would provide further support for the cognitive-motivational theory of alcoholism. Second, we used data on a battery of cognitive tasks (including three measures of WM updating) collected from a separate sample of young adults (age 21–35) to investigate whether these interaction effects can also be found using WM updating. If measures of WM updating do not moderate associations between impulsivity and alcohol involvement, this would suggest that the cognitive-motivational theory of alcoholism is specific to WM capacity. Although distinct in these aspects, both samples have been administered similar measures of impulsivity and alcohol involvement, making both datasets informative for extending work in this area.

2. Study 1: materials and methods

2.1. Participants

Participants in the Alcohol, Health, and Behavior (AHB) Study were 489 first-year college students from a large midwestern university at the first wave of data collection (*M* age = 18.2 years; 46% male; 94% Caucasian). There have since been six additional waves of data collection (ages 19, 20, 21, 25, 29, and 35), with a 78% retention rate at the last wave of data collection. Half of the sample (51%) were classified as family history positive for an alcohol use disorder, based on adaptations of the Short Michigan Alcoholism Screening Test (F-SMAST and M-SMAST; T. M. Crews & Sher, 1992) and the Family History-Research Diagnostic Criteria interview (FH-RDC; Endicott, Andreasen, & Spitzer, 1978) (see Sher, Walitzer, Wood, & Brent, 1991 for a full description of the study). All data collection was approved by the Institutional Review Board (IRB) at the University of Missouri.

2.2. Measures

2.2.1. Alcohol involvement

Descriptive statistics for the AHB sample on all measures are displayed in Table 1. Two measures of alcohol use, capturing normative use (quantity and frequency) and heavy drinking (i.e., intoxication and binge drinking frequency) were administered to the AHB sample at each wave of data collection. A measure referred to as alcohol quantity–frequency (QF; Jackson & Sher, 2006) was calculated as the typical quantity (average number of drinks per occasion) multiplied by the frequency of drinking (per week). In addition, a heavy drinking composite captured the frequency of getting “a little high or light-headed on alcohol”, “drunk (not just a little high)” and binge drinking in the previous 30 days. Items comprising the heavy drinking composite have demonstrated adequate internal consistency in the AHB (α = .91; Sher et al., 1991).

Table 1
Descriptive statistics for measures of alcohol involvement, impulsivity, and working memory capacity in the Alcohol, Health, and Behavior (AHB) sample.

Measure	Mean	SD	Skewness	Kurtosis
Alcohol involvement				
Quantity–frequency	8.03	13.30	0.23	−0.78
Heavy drinking	0.76	0.94	0.91	0.30
Alcohol-related consequences	1.59	1.82	0.32	−1.18
Alcohol dependence	2.12	1.88	−0.08	−0.67
Impulsivity				
Social deviance	6.93	3.69	0.53	0.32
TPQ NS Exploratory Excitability	5.51	1.75	−0.26	−0.34
TPQ NS Impulsiveness	3.29	2.20	0.23	−0.97
TPQ NS Extravagance	3.82	1.81	−0.25	−0.67
TPQ NS Disorderliness	5.50	2.00	0.08	−0.67
Working memory capacity				
Digit-span backward	7.36	2.27	0.40	0.05
Digit-span forward	8.90	2.11	0.07	−0.53
Digit-span total	16.26	3.71	0.30	−0.05

Note: All descriptive statistics for measures in AHB were collected at Wave1. Means and standard deviations for measures of alcohol involvement are from raw data, but skewness and kurtosis statistics are for log-transformed data.

Two measures of problematic alcohol use were also assessed at each wave of AHB data collection. First, alcohol-related consequences were calculated, based on 27 items consistent with theoretical conceptualizations of alcohol dependence syndrome (Edwards & Gross, 1976). Items comprising this measure of alcohol-related consequences have demonstrated adequate internal consistency in the AHB sample across all waves (α = .87–.90; Littlefield et al., 2009). Second, the AUD section of the Diagnostic Interview Schedule, version III-A (DIS-IIIA; Robins, Helzer, Croughan, Williams, & Spitzer, 1985) was used to assess endorsement of past-year alcohol dependence symptoms. The DIS is a semi-structured interview that assesses psychiatric diagnostic information, and a version based on the *Diagnostic and Statistical Manual of Mental Disorders, Third Edition* (DSM-III; American Psychiatric Association, 1980) was administered at the first wave of data collection. In subsequent waves of data collection, newer versions of the DIS were employed as they became available for assessing DSM-III-R (Robins, Helzer, Cottler, & Goldring, 1989) and DSM-IV (Robins, Cottler, Bucholz, & Compton, 1995). To maintain compatibility with prior versions, earlier DIS questions were included along with the updated DIS version in later waves to enable consistency in how dependence is operationalized and diagnosed across waves.

2.2.2. Impulsivity

AHB participants completed, among other scales, the Pd (scale 4) and Ma (scale 9) subscales of the 168-item short-form of the Minnesota Multiphasic Personality Inventory (MMPI-168; Hathaway & McKinley, 1943; Overall & Gomez-Mont, 1974), from which the Psychopathic Deviance scale was used to measure social deviance. In addition to querying about behaviors specific to delinquency (e.g., “engaged in petty thievery as a youngster”, “sent to principal's office”), this scale contains general items that appear to measure the facets of impulsivity, such as lack of planning (e.g., “I do many things I regret afterward”), lack of perseverance (e.g., “hard to keep my mind on task”), and sensation seeking (e.g., “daily life is full of things that keep me interested”—reverse scored). This scale was included to follow-up prior empirical work testing the cognitive-motivational theory of alcoholism (Finn & Hall, 2004). Internal consistency of this measure was demonstrated in the AHB sample (α = 0.79).

Participants also completed the Tridimensional Personality Questionnaire (TPQ; Cloninger, 1987), from which the Novelty Seeking scale was used. The Novelty Seeking scale is composed of several subscales including Exploratory Excitability (e.g., “When nothing new is happening, I usually start looking for something that is thrilling or exciting”), Impulsiveness (e.g., “I often follow my instincts, hunches, or intuition without thinking through all the details”), Extravagance (e.g., “I often spend money until I run out of cash or get into debt”), and Disorderliness (e.g., “I like it when people can do whatever they want without strict rules/regulations”). Whereas Exploratory Excitability appears to measure trait sensation seeking, the remaining measures appear to measure lack of planning, with Impulsiveness reflecting a general tendency to act without thinking, and Extravagance and Disorderliness reflecting this tendency more specific to spending and rule breaking, respectively. Internal consistency was demonstrated with the total TPQ Novelty Seeking scale (α = 0.79), the TPQ Impulsiveness subscale (α = 0.70), and the TPQ Extravagance subscale (α = 0.68). Internal consistency may be a concern for the TPQ Exploratory Excitability (α = 0.49) and Disorderliness (α = 0.51) subscales, however.

2.2.3. Working memory

Participants in the AHB sample were administered cognitive tests to assess various domains of cognitive functioning, including WM. Attention, concentration, and WM were assessed using the digit span subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). This subtest includes tasks that involve recalling digits forward (i.e., in the same order in which they were delivered) and backward (i.e., in the reverse-order in which they were delivered). Digit-span recall has been shown to load on a WM capacity factor (Engle & Kane, 2003), suggesting that it is a measure of an individual's ability to store and maintain information in WM. Recalling digits backward requires some of the same ability as recalling digits forward (Thomas, Milner, & Haberlandt, 2003), however, it is also related to processes independent of forward recall, such as the ability to manipulate information (Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000). Whereas forward recall appears to tap phonological processes, backward recall additionally taps WM as it relates to executive (Lezak, 1995) and planning (Schofield & Ashman, 1986) processes. The current study, therefore, measured WM with backward digit-span recall, as executive and planning processes are of direct interest to alcohol involvement.

2.3. Analytic approach

2.3.1. Cross-sectional moderation of working memory capacity on impulsivity and alcohol involvement

All regression models were conducted in SAS 9.2 (SAS Institute, 2009). First, regression models were developed in an effort to replicate previous moderation effects of digit-span recall on the relationship between impulsivity and alcohol involvement (e.g., Finn & Hall, 2004). In addition to including effects to test for moderation (main effects of digit-span recall and impulsivity and an interaction effect of the two), models included quadratic effects (to control for spurious interactions; Lubinski & Humphreys, 1990) and main effects of control covariates (sex and family history of AUD, to control for gender differences and risk of AUD in study variables, and vocabulary to control for overall cognitive ability). Outlying observations (n = 32–43) with excessive influence on model results were dropped, as indicated by leverage greater than twice the sample mean.

2.3.2. Prospective moderation of working memory capacity on impulsivity and alcohol involvement

To follow-up tests of digit-span recall as a cross-sectional moderator of impulsivity and alcohol involvement, regression models were tested for this same effect prospectively. These models followed the same structure as those testing for cross-sectional moderation, except that digit-span recall and impulsivity were measured at baseline (age 18) and alcohol was measured at each subsequent wave of data collection. In addition, models included the same quadratic effects and covariates as the cross-sectional models. Using the leverage statistic and the same criteria described above, outlying observations with excessive influence were again dropped (n = 12–13).

3. Study 1: results

3.1. Cross-sectional moderation of working memory capacity on impulsivity and alcohol involvement

Regression models were tested for moderation effects of digit-span recall on the relationship between five personality measures (Psychopathic Deviance from the MMPI and Exploratory Excitability, Impulsiveness, Extravagance, and Disorderliness from the TPQ) and four alcohol outcomes (alcohol use, heavy drinking, alcohol consequences, and alcohol dependence). The standardized regression coefficients for the main effects of impulsivity and digit-span recall, as well as their interaction effect, are displayed in Table 2. For all models, main effects of digit-span recall on alcohol outcomes did not reach statistical significance. There were main effects of social deviance [$Fs(1, 435) = 12.26–18.25$, $ps < .0005$], TPQ Exploratory Excitability subscale [$Fs(1, 442) = 9.78–22.89$, $ps < .002$], TPQ Impulsiveness subscale [$Fs(1, 441) = 16.22–24.64$, $ps < .0001$], TPQ Extravagance subscale [$Fs(1, 437) = 16.96–37.11$, $ps < .0001$], and TPQ Disorderliness subscale [$Fs(1, 431) = 22.93–43.84$, $ps < .0001$] on all alcohol outcomes. In addition, WM capacity moderated the relationship between all alcohol outcomes and social deviance, except alcohol dependence [$Fs(1, 435) = 1.8–7.32$, $ps = .01–.18$], as well as alcohol-related consequences and the TPQ Exploratory Excitability subscale [$F(1, 442) = 5.04$, $p = .03$] and TPQ Extravagance subscale [$F(1, 437) = 7.68$, $p = .01$]. There was no evidence of digit-span recall moderating the association between the TPQ Impulsiveness subscale [$Fs(1, 441) = 0.00–1.71$, $ps = .19–.96$] or TPQ Disorderliness subscale [$Fs(1, 431) = 0.20–1.83$, $ps = .18–.65$].

Plots displaying the nature of these interactions show that, as expected, moderation effects were such that relationships between alcohol involvement and impulsivity measures were strongest in individuals who demonstrated poor WM capacity. That is, Fig. 1 shows the data surface on the left-hand side of plots, where participants were lowest in digit-span recall, demonstrated the steepest curve representing strong associations between increasing social deviance and increasing

Table 2
Regression coefficients and standard errors for tests of main and interaction effects of impulsivity and digit span on alcohol involvement using AHB data.

Effect	Social deviance	Exploratory Excitability	Impulsiveness	Extravagance	Disorderliness
Heavy drinking					
Impulsivity	2.37 (0.63)***	5.30 (1.23)***	4.72 (0.95)***	6.46 (1.18)***	7.23 (1.09)***
Digit span	1.04 (1.03)	0.19 (1.03)	0.89 (1.01)	0.65 (1.02)	0.36 (1.01)
Impulsivity * digit span	−0.71 (0.34)*	−0.24 (0.68)	0.65 (0.49)	−0.65 (0.68)	−0.34 (0.61)
*Alcohol use (quantity * frequency)*					
Impulsivity	5.60 (1.60)***	14.69 (3.07)***	10.63 (2.41)***	18.00 (2.95)***	17.89 (2.71)***
Digit span	3.28 (2.63)	2.63 (2.57)	3.26 (2.56)	2.28 (2.55)	1.27 (2.51)
Impulsivity * digit span	−2.26 (0.86)**	−2.46 (1.71)	−0.20 (1.25)	−0.64 (1.71)	−2.04 (1.51)
Alcohol dependence					
Impulsivity	3.66 (0.86)***	5.33 (1.7)**	5.31 (1.32)***	7.86 (1.66)***	7.28 (1.52)***
Digit span	0.33 (1.41)	0.10 (1.43)	0.51 (1.40)	0.81 (1.43)	0.17 (1.41)
Impulsivity * digit span	−0.62 (0.46)	−0.85 (0.95)	−0.18 (0.68)	−1.66 (0.96)	−0.38 (0.85)
Alcohol-related consequences					
Impulsivity	3.62 (0.97)***	6.52 (1.88)***	6.48 (1.46)***	7.52 (1.83)***	8.42 (1.71)***
Digit span	0.62 (1.58)	−0.49 (1.57)	−0.05 (1.55)	0.04 (1.58)	−0.46 (1.58)
Impulsivity * digit span	1.40 (0.52)**	−2.35 (1.05)*	−0.04 (0.76)	−2.93 (1.06)**	−0.89 (0.95)

Note: Regression coefficients and standard errors were multiplied by 100 for ease of interpretation. Digit-span recall is measured as the raw scores on the digit-backward task. Measures of impulsivity and digit-span recall were centered and quadratic terms of both were modeled. All alcohol outcomes were log-transformed to account for non-normality of data. Covariates included sex and family history (both dichotomized) and vocabulary (to control for general cognitive ability) but did not include baseline measures of alcohol involvement to account for autoregressivity.

*** $p < .001$.
** $p < .01$.
* $p < .05$.

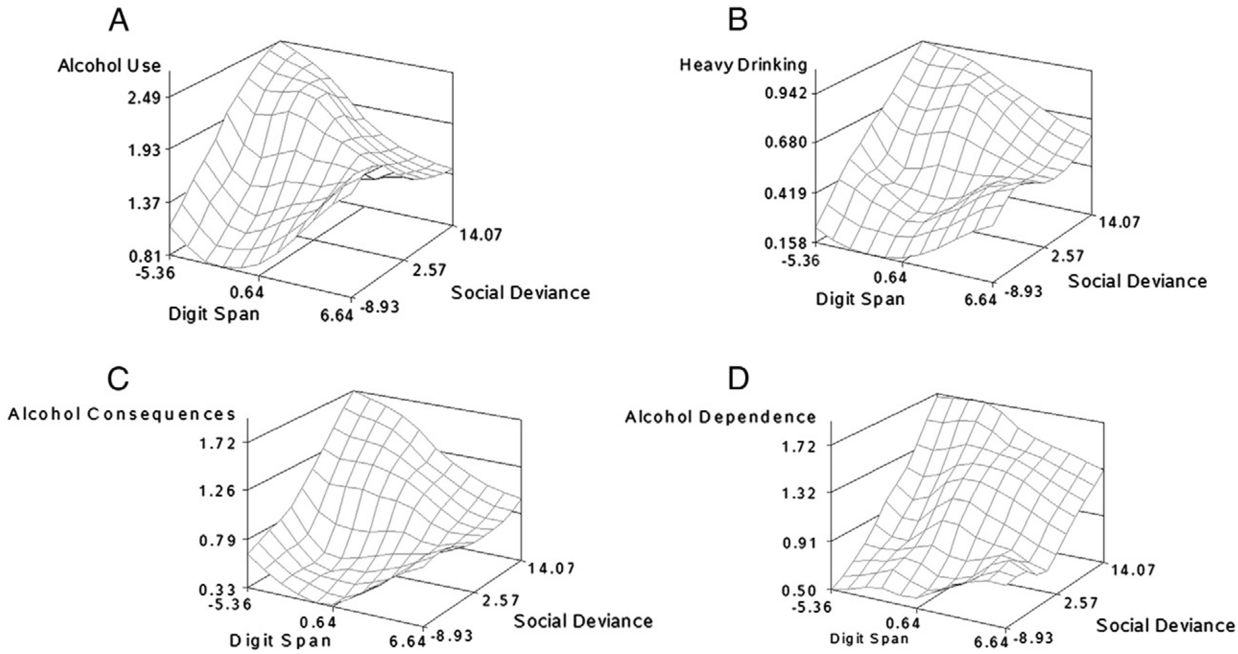

Fig. 1. The moderation effects of digit span recall on the relationship between social deviance and alcohol involvement are displayed for (A) alcohol quantity–frequency, (B) heavy drinking, (C) alcohol related consequences, and (D) alcohol dependence. All interactions are such that, associations between social deviance and alcohol involvement are strongest in individuals performing poorly on the digit-span recall test.

(A) alcohol use, (B) heavy drinking, and (C) alcohol consequences. In contrast, the data surface on the right-hand side of each figure, where participants were highest in digit-span recall, demonstrated almost no noticeable curve, representing no association between social deviance and alcohol involvement. In Fig. 2, a similar but less pronounced pattern was observed for alcohol-related consequences with the TPQ subscales of (A) Exploratory Excitability and (B) Extravagance. Digit-span recall did not moderate the relationship between social deviance and alcohol dependence, however (see Fig. 1D). That is, there was no consistent pattern in the data surface representing the association between social deviance and alcohol dependence, across levels of digit-span recall.

3.2. Prospective moderation of working memory capacity on impulsivity and alcohol involvement

Given that social deviance was the only impulsivity measure that yielded interaction effects across multiple alcohol outcomes in cross-sectional analyses, additional tests of digit-span recall moderating the association between social deviance and prospective alcohol involvement were conducted (see Table 3 for standardized regression coefficients for main and interaction effects). This moderation effect prospectively predicted alcohol use through Wave 4 [age 21; $Fs(1, 454) = 4.08$–8.91, $ps = .003$–$.04$] and alcohol-related consequences through Wave 3[age 20; $Fs(1, 455) = 4.20$–7.65, $ps = .01$–$.04$], and it approached statistical significance for alcohol dependence at Wave 3 [age 20; $F(1, 455) = 3.72$, $p = .054$]. After accounting for initial measures of alcohol involvement at Wave 1, however, only one moderation effect (alcohol use at Wave 2) remained statistically significant [$F(1, 467) = 5.05$, $p = .03$]. That is, although we found considerable support for lagged effects when autoregressivity was not modeled, most of these effects were no longer significant when corresponding measures of baseline alcohol involvement were modeled as exogenous variables.

Although there were significant interaction effects in cross-sectional models of TPQ Exploratory Excitability and Extravagance, there were no prospective moderation effects of alcohol outcomes for either of these personality measures [$Fs(1, 360$–$468) = 0.00$–2.82, $ps = .09$–$.98$]. Notably, these cross-sectional interaction effects appeared less pronounced than for those of social deviance.

4. Study 2: materials and methods

4.1. Participants

Participants in Midwest Alcoholism Research Center (MARC) Project 8 were 420 adults aged 21–35 (M age = 23.1 years; 51% male, 90% Caucasian) recruited from a midwestern community for a study on

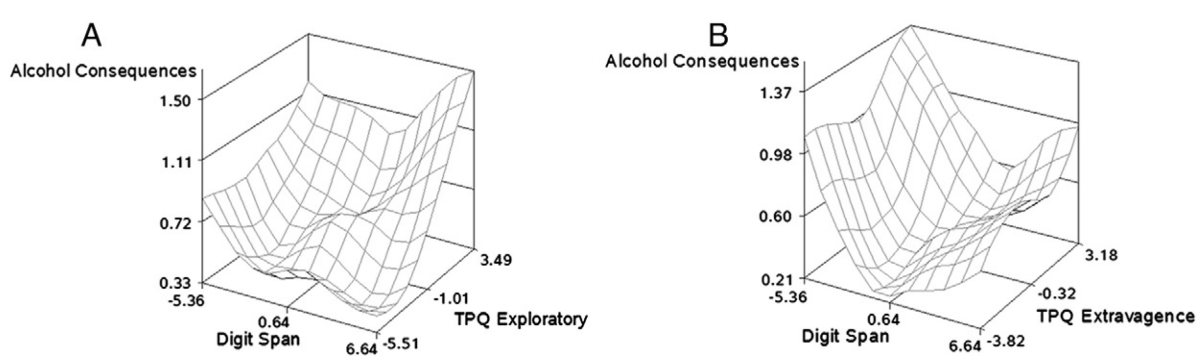

Fig. 2. The moderation effects of digit span recall on the relationship between alcohol consequences and (A) the TPQ Exploratory Excitability subscale and (B) the TPQ Extravagance subscale.

Table 3
Regression coefficients and standard errors of prospective main and interaction effects of social deviance and digit span recall on alcohol involvement using AHB data.

Effect	Wave 2	Wave 3	Wave 4	Wave 5	Wave 6	Wave 7
Heavy drinking						
Social deviance	1.59 (0.59)**	1.48 (0.59)*	1.64 (0.58)**	1.29 (0.52)*	1.27 (0.49)**	1.80 (0.52)***
Digit span	0.42 (0.87)	0.66 (0.88)	0.17 (0.86)	1.31 (0.77)	−0.94 (0.73)	−0.23 (0.76)
Social deviance * digit span	−0.33 (0.25)	−0.43 (0.25)	−0.20 (0.25)	−0.06 (0.22)	−0.06 (0.20)	0.01 (0.22)
*Alcohol use (quantity * frequency)*						
Social deviance	4.55 (1.48)**	3.80 (1.46)**	3.48 (1.37)*	3.52 (1.43)*	3.83 (1.40)**	3.82 (1.49)*
Digit span	0.28 (2.21)	2.33 (2.19)	1.66 (2.04)	2.93 (2.13)	2.08 (2.08)	1.00 (2.18)
Social deviance * digit span	−1.89 (0.63)**	−1.26 (0.63)*	−1.21 (0.58)*	−0.41 (0.61)	−0.50 (0.59)	−0.16 (0.62)
Alcohol dependence						
Social deviance	2.47 (0.82)**	2.85 (0.83)***	2.15 (0.84)*	1.63 (0.82)*	2.04 (0.76)**	1.98 (0.82)*
Digit span	−0.41 (1.22)	−1.31 (1.25)	−0.06 (1.26)	0.37 (1.22)	0.54 (1.13)	−0.60 (1.21)
Social deviance * digit span	−0.44 (0.35)	−0.69 (0.36)	−0.53 (0.36)	0.35 (0.35)	0.17 (0.32)	−0.18 (0.34)
Alcohol-related consequences						
Social deviance	2.78 (0.86)**	3.21 (0.86)***	0.79 (0.85)	1.99 (0.77)**	1.36 (0.72)	1.66 (0.71)*
Digit span	1.06 (1.28)	0.06 (1.29)	1.34 (1.26)	1.14 (1.14)	0.99 (1.07)	−0.53 (1.04)
Social deviance * digit span	−1.02 (0.37)**	−0.76 (0.37)*	−0.65 (0.36)	0.03 (0.33)	−0.17 (0.30)	−0.16 (0.30)

Note: Regression coefficients and standard errors were multiplied by 100 for ease of interpretation. Social deviance is measured by the Psychopathic Deviance scale from the Minnesota Multiphasic Personality Inventory. Both social deviance and digit span recall were centered, and all alcohol outcomes were log-transformed to account for the non-normality of data.
*** $p < .001$.
** $p < .01$.
* $p < .05$.

the effects of alcohol on cognition. Potential participants were interviewed via telephone and asked a number of questions about their medical history, general health, and history of substance use and abuse. Individuals with conditions contraindicating participation in an alcohol challenge (e.g., abstention; history of alcohol or drug dependence or other serious mental or physical illness; prescription medication other than oral contraception; pregnancy) or that would make completion of laboratory tasks unusually difficult (e.g., colorblindness; a primary language other than English) were excluded from the sample. In addition, to ensure that the alcohol dose received in the study would be within participants' normal range of experience, naïve drinkers (i.e., individuals reporting an average of less than 2 drinks per week) and very heavy drinkers (individuals reporting an average of 25 or more drinks per week) were excluded from the study sample. All data collection was approved by the IRB at the University of Missouri.

4.2. Measures

4.2.1. Alcohol involvement

Descriptive statistics for the Project 8 sample on all measures are displayed in Table 4. Alcohol use in Project 8 was based on the same alcohol QF measure used in the AHB sample, multiplying per week estimates of the number and frequency of alcoholic drinks, based on the past month reports. Heavy drinking was measured using the number of binge (4+ drinks in one sitting for women, 5+ for men) episodes over the past month.

Table 4
Descriptive statistics for measures of alcohol involvement, impulsivity, and working memory updating in the Project 8 sample.

Measure	Mean	SD	Skewness	Kurtosis
Alcohol involvement				
Quantity–frequency	7.23	6.50	−0.07	−0.70
Heavy drinking	1.60	1.24	−0.41	−1.16
Alcohol-related consequences	1.47	1.61	0.43	−0.51
Lifetime alcohol dependence	1.51	1.83	0.39	−1.11
Current alcohol dependence	1.01	1.60	0.94	−0.09
Impulsivity				
Social deviance	4.85	1.32	−0.10	−0.83
TPQ NS Exploratory Excitability	5.80	1.78	−0.67	0.17
TPQ NS Impulsiveness	2.40	1.87	0.54	−0.64
TPQ NS Extravagance	3.35	1.72	−0.10	−0.58
TPQ NS Disorderliness	4.39	2.19	0.12	−0.74
Working memory updating				
Keep track	70.44	10.76	−0.27	−0.22
Letter memory	76.07	13.97	−0.16	−0.86
Spatial 2-back	80.97	7.89	−0.05	−0.16
Updating factor	0.00	4.63	−0.16	−0.69

Note: Means and standard deviations for measures of alcohol involvement are from raw data, but skewness and kurtosis statistics are for log-transformed data.

Participants in Project 8 completed an alcohol problems measure that was derived from the Rutgers Alcohol Problems Index (White & Labouvie, 1989) and Young Adult Alcohol Problems Screening Test (Hurlbut & Sher, 1992), which tap the severity and type of negative consequences associated with drinking in a number of domains. Specifically, this measure contains 36 items assessing health-related problems (e.g., passing out, throwing up, injuring yourself), work and school-related problems (e.g., missing work or school due to drinking or hangover, gotten in trouble at work/school because of drinking), interpersonal and relationship problems (e.g., lost friends/significant others because of drinking, gotten into fights while drunk), legal problems (e.g., been arrested for drunken behaviors, driven a car while drunk), and problems indicative of alcohol dependence (e.g., withdrawal symptoms when trying to cut back, inability to stop, drinking more than intended). Participants indicated whether they ever experienced each problem, and if so, how often and how recently (i.e., past month, past year, >1 year). In addition, a diagnostic measure was based on self-reported endorsement of DSM-IV alcohol use disorder criteria, which were used to create sum measures of lifetime and past year alcohol dependence symptoms.

4.2.2. Impulsivity

Project 8 participants were administered the NEO-FFI (Costa & McCrae, 1989), as well as the Novelty-Seeking scale from the TPQ (Cloninger, 1987). Factor analyses were performed on items from the NEO to extract a measure of social deviance similar to the MMPI-168 Psychopathic Deviance scale (e.g., "I often break rules and regulations when I think I can get away with it"). In addition, the same TPQ Novelty Seeking subscales used in AHB were used in Project 8, however, five items were dropped due to weak correlations with other items on the scale. Internal consistency was demonstrated for the measure of social deviance ($\alpha = 0.69$), the total TPQ Novelty Seeking scale ($\alpha = 0.78$), the TPQ Impulsiveness subscale ($\alpha = 0.70$), and the TPQ Extravagance subscale ($\alpha = 0.70$). As with AHB, however, internal consistency may be a concern for the TPQ Exploratory Excitability subscale ($\alpha = 0.58$) and Disorderliness subscale ($\alpha = 0.63$).

4.2.3. Working memory

A primary aim of Project 8 was to characterize individual differences in EF using the 3-factor latent variable model proposed by Miyake et al. (2000). Thus, Project 8 participants completed twelve task measures of EF that comprise this factor model, including three measures of WM updating. The Project 8 data have demonstrated adequate fit to the EF factor model proposed by Miyake et al. (2000). Participant factor scores of WM updating were analyzed, however, the three measures comprising this factor are described below.

The *keep track* task (adapted from Yntema, 1963) required participants to track a series of exemplars belonging to six different categories. Each trial began with a list of 3–5 target categories (animals, colors, countries, distances, metals, and relatives) shown at the bottom of the computer screen. At the beginning of each trial, "GET READY" appeared for 2 s, and following a 1 s blank screen, the categories appeared at the bottom of the screen and remained while a stream of 15–25 exemplar words from all six categories appeared in the center of the screen at a rate of one word every 2 s. At the end of the trial, "???" appeared in the center of the screen, indicating that the participant should verbally recall the most recent exemplar from each target category. Participants were not allowed to recall the words or categories aloud during the course of each trial. Participants practiced on three trials, then performed 12 trials (four of each difficulty level, presented in random order), recalling a total of 36 words. The proportion of words recalled correctly is the dependent measure.

In the *letter memory* task (adapted from Morris & Jones, 1990), several letters from a list were presented in the center of the screen serially for 2500 ms per letter. The task is to recall the last four letters in the correct order. To ensure that the task required continuous updating, participants were instructed to rehearse aloud the most recent four letters by mentally adding the most recent letter, dropping the fifth letter back, and then saying aloud the new string of four letters. For example, if the letters presented are, "T, H, G, B, S, K, R," the participants should say, "T … TH … THG … THGB … HGBS … GBSK … BSKR," and then recall "BSKR" at the end of the trial. The number of letters presented (7, 9, or 11) is varied randomly across trials, with the constraint that each list length is used once in every three trials. After 7, 9, or 11 letters had appeared, "???" appeared on the screen, indicating that the participant should report the final 4 letters in the correct order. Participants are instructed to recall the letters in order and to say "blank" if they do not remember a particular letter. However, answers are scored as correct even if the letters are not recalled in the correct order. After practicing on three trials (one of each length), participants completed 12 critical trials (four of each length). The dependent measure is the proportion of letters correctly recalled across all lists.

In each block of the *spatial 2-back* task (see Friedman et al., 2008; Kirchner, 1958; Owen, McMillan, Laird, & Bullmore, 2005), there were 12 open squares (5/8 in) arranged in a fixed pseudorandom location on the computer screen, such that, if the screen was divided into quadrants, 3 squares were positioned in each quadrant. On each trial, one box becomes solid black for 500 ms, giving the appearance of a flash. On each trial, participants judged whether the current stimulus appeared in the same location as the stimulus that appeared two trials earlier. There were 1500 ms between each flash (24 flashes per block). Participants complete one practice block followed by four actual blocks. The dependent measure is the proportion of correct responses (yes and no) across all four blocks. Omissions are counted as incorrect responses.

4.3. Analytic approach

4.3.1. Moderation of working memory updating on impulsivity and alcohol involvement

To follow-up the moderation effect of digit-span recall on the relationship between impulsivity and alcohol involvement in Study 1, regression models were tested for this same effect in the WM updating factor. These models followed the same structure as the initial model testing digit-span recall as a moderator, however, other measures of intelligence (e.g., verbal ability) were not available in Project 8 and could not be statistically controlled. As in Study 1, outlying observations with excessive influence were dropped ($n = 27–49$).

5. Study 2: results

5.1. Moderation of working memory updating on impulsivity and alcohol involvement

First, regression models were conducted on a factor score of the three measures of WM updating (see Table 5 for standardized regression coefficients for main and interaction effects). Social deviance was associated with nearly all alcohol outcomes, except lifetime alcohol dependence symptoms [$Fs(1, 375) = 3.38–26.32$, $ps = .0001–.07$], and the TPQ Disorderliness subscale was associated with all alcohol outcomes [$Fs(1, 355) = 4.34–26.47$, $ps = .0001–.04$]. Only some alcohol measures were associated with the TPQ Exploratory Excitability [$Fs(1, 361) = 0.02–7.17$, $ps = .01–.88$] and TPQ Impulsiveness subscales [$Fs(1, 369) = 0.06–7.58$, $ps = .01–.81$], and there were no statistically significant associations with the TPQ Extravagance subscale [$Fs(1, 357) = 0.09–3.36$, $ps = .07–.76$]. Notably, alcohol-related consequences were associated with all impulsivity measures, except TPQ Extravagance. Moderation effects of the WM updating factor were not statistically significant for any personality trait or alcohol outcome [$Fs(1, 355–375) = 0.00–2.38$, $ps = .12–.98$].[1]

6. Discussion

The current study attempted to replicate and extend prior work on the cognitive-motivational theory of personality vulnerability to alcoholism, which posits that WM moderates the relationship between impulsivity and alcohol involvement. Study 1 replicated prior investigations of this theory (Finn & Hall, 2004), as WM capacity moderated the relationship between alcohol involvement and three personality measures, the MMPI Psychopathic Deviance scale (i.e., trait social deviance), TPQ Exploratory Excitability subscale (i.e., trait sensation seeking), and TPQ Disorderliness subscale (i.e., delinquent behavior related to trait lack of planning). Further, prospective analyses showed that interactions between WM capacity and social deviance predicted alcohol involvement up to three years prospectively. It is important to note, however, that prospective moderation effects did not persist after accounting for baseline measures of alcohol use. Prospective moderation effects should, therefore, be interpreted with caution.

To test whether this moderation effect applies to other components of WM (e.g., Miyake & Friedman, 2012), Study 2 was conducted using WM updating. These analyses did not yield any moderation effects for the WM updating factor on measures of impulsivity and alcohol involvement. Considering these findings, it appears that WM capacity, but not WM updating, moderates the relationship between some measures of impulsivity and alcohol involvement.

The moderation effects in Study 1 replicate and extend previous empirical (Finn & Hall, 2004) and theoretical (Finn, 2002) work on the cognitive-motivational theory of alcoholism. In particular, the current findings may provide suggestions to key research questions posed by this theory: "What are the mechanisms for association between (personality) traits and alcohol use disorders?" (Finn, 2002, p. 184). These

[1] Analyses also investigated whether specific measures of WM updating, which may tap specific aspects of WM updating (e.g., verbal vs. spatial information), moderate associations between measures of impulsivity and alcohol involvement. Across all three tasks (keep track, letter memory, spatial 2-back), only two moderation effects reached statistical significance, with performance on the spatial 2-back task moderating the association between current alcohol dependence symptoms and both social deviance [$F(1, 348) = 5.51$, $p = .02$] and the TPQ Impulsiveness subscale [$F(1, 338) = 4.48$, $p = .03$]. Considering the number of tests involved in these specific measures, however, these associations should be interpreted with caution.

Table 5
Regression coefficients and standard errors for tests of main and interaction effects of impulsivity and working memory updating on alcohol use outcomes using MARC Project 8 data.

Effect	Social deviance	Exploratory Excitability	Impulsiveness	Extravagance	Disorderliness
Alcohol use (quantity ∗ frequency)					
Impulsivity	−16.22 (3.31)***	0.42 (2.86)	3.26 (2.42)	4.78 (2.61)	6.85 (2.08)**
WMU	0.99 (0.90)	0.83 (0.97)	0.48 (0.93)	1.16 (0.95)	0.40 (0.94)
Impulsivity ∗ WMU	1.10 (0.83)	0.74 (0.74)	−0.71 (0.58)	0.34 (0.68)	−0.13 (0.52)∝
Heavy drinking (binge in last 30 days)					
Impulsivity	−7.70 (2.35)**	2.59 (1.88)	4.04 (1.67)*	1.99 (1.83)	3.68 (1.46)*
WMU	0.61 (0.64)	0.56 (0.67)	0.29 (0.64)	0.65 (0.67)	0.33 (0.66)
Impulsivity ∗ WMU	0.50 (0.59)	0.01 (0.50)	−0.33 (0.40)	−0.39 (0.48)	0.03 (0.37)
Alcohol-related consequences					
Impulsivity	−12.33 (2.40)***	5.30 (1.98)**	4.83 (1.75)**	1.66 (1.93)	7.60 (1.48)***
WMU	−0.25 (0.66)	0.16 (0.70)	−0.41 (0.68)	0.01 (0.71)	−0.29 (0.67)
Impulsivity ∗ WMU	0.78 (0.60)	0.12 (0.53)	0.04 (0.42)	−0.02 (0.51)	−0.56 (0.37)
Lifetime alcohol dependence symptoms					
Impulsivity	−5.47 (2.98)	4.42 (2.36)	−0.51 (2.13)	0.71 (2.33)	3.84 (1.84)*
WMU	−0.04 (0.81)	−0.48 (0.84)	−0.15 (0.82)	−0.23 (0.86)	−0.02 (0.84)
Impulsivity ∗ WMU	−0.49 (0.75)	−0.20 (0.63)	0.37 (0.51)	0.77 (0.61)	0.15 (0.46)
Current alcohol dependence symptoms					
Impulsivity	−7.52 (2.64)**	−1.75 (2.12)	3.60 (1.86)	−0.75 (2.06)	3.71 (1.60)*
WMU	0.39 (0.72)	0.38 (0.75)	0.19 (0.72)	0.18 (0.76)	−0.06 (0.73)
Impulsivity ∗ WMU	0.08 (0.66)	0.30 (0.57)	0.05 (0.45)	−0.15 (0.54)	−0.16 (0.40)

Note: Regression coefficients and standard errors were multiplied by 100 for ease of interpretation. Working memory updating (WMU) is measured as a factor score of performance on the keep track, letter memory, and spatial 2-back tasks. Covariates included sex and family history of alcohol dependence (both dichotomized). All alcohol outcomes are log-transformed to account for the non-normality of data.
*** $p < .001$.
** $p < .01$.
* $p < .05$.

findings suggest that impulsivity increases liability for alcohol use and AUD primarily in individuals with deficits in EF, specifically WM capacity. The cognitive-motivational theory of alcoholism posits that such effects occur for three primary reasons: (1) WM is limited in the amount of information it can handle (Cowan, 2001), (2) WM serves as a filter for information that is incorporated into decision making, and (3) information with greater salience takes precedence for the limited capacity of WM (Finn, 2002). As applied to the current findings, individual differences in impulsivity may determine the salience of different kinds of information, thereby influencing which stimuli are held in WM. It follows, then, that behavior should correlate most strongly with underlying traits in individuals with less WM capacity, who are less able to handle information that is unrelated to, or inconsistent with, basic motivational propensities.

This conceptualization is similar to empirical and theoretical work on dual-systems models of alcohol involvement (e.g., Houben & Wiers, 2009; Hutchison, 2010), which suggest that problematic alcohol use is the consequence of an interaction between an affective-based system (e.g., urges to drink) and cognitive-based system (e.g., the ability to control drinking). Notably, empirical studies of these dual-systems models have found interactions similar to those in Study 1, with alcohol involvement being predicted by an interaction between WM capacity and behavioral measures of affective-based processes (e.g., Implicit Association Test; Thush et al., 2008). Further, other tests of this model have shown similar moderation effects involving cognitive processes other than WM capacity (e.g., performance on the Stroop Task; Houben & Wiers, 2009). Notably, animal models have shown that WM is impaired and impulsivity is elevated when exposed to chronic stress (e.g., Mika et al., 2012), which is similar to the relationship between alcohol involvement and urgency, a facet of impulsivity that appears to be an amalgam of affective and cognitive processes (i.e., the tendency to engage in impulsive behavior when experiencing intense affect; Cyders & Smith, 2008).

Despite a wealth of evidence on the associations between EF (of which WM is a component), impulsivity, and alcohol use (e.g., Finn, Justus, Mazas, & Steinmetz, 1999), conclusions reached in the literature are far from consistent. For example, these effects were not found when using WM updating in Study 2, and at least one attempt to replicate the interaction effect in dual-systems models failed to find similar effects when using alcohol expectancies as a measure of these affective processes (Littlefield, Vergés, McCarthy, & Sher, 2011). A primary source of this inconsistency, therefore, likely lies in the complexity and inconsistency in how different research groups define and measure cognitive (e.g., EF; Jurado & Rosselli, 2007; Miyake et al., 2000) and affective processes (e.g., self-reported traits vs. behavioral measures; Littlefield et al., 2011; Thush et al., 2008).

The current studies highlight this problem, particularly in regard to defining and measuring EF. Miyake and Friedman (2012) pointed out the major problem of task impurity in the measurement of EF, whereby a task purported to measure some component of EF necessarily also taps some systematic, task-specific, non-EF related variance, thereby limiting the interpretation of effects. This problem is exacerbated by the overwhelming reliance in clinical psychological research on using a single task to measure complex cognitive processes, like WM. Recently, Ecker et al. (2010) used structural equation modeling to investigate the relation between WM capacity and WM updating component processes (retrieval, transformation, substitution). These authors found that retrieval and transformation were significantly predicted by WM capacity ability, but that substitution was unique to WM updating and not predicted by WM capacity. Evaluating the tasks used in studies of WM ability would likely reveal a number of construct-related differences that explain many inconsistencies in the extant literature. Within the current study, it may be of interest that the *spatial 2-back* task was the only measure of WM updating that demonstrated any moderation effect (see Future directions section).

It should also be noted that prior work with the AHB sample has revealed change in impulsivity over early and middle adulthood, and these changes correlate with changes in drinking (Littlefield et al., 2009). Given that the frontal lobes continue to develop well into the third-decade of life (Steinberg, 2010), it is likely that we might see systematic change in WM as a function of age. Consequently, both WM and impulsivity should be viewed as more dynamic than is typically assumed in the literature. This may be particularly important in regard to interpreting results in the current paper, as impulsivity and WM measures were collected towards the end of adolescence in the AHB sample (mean age = 18.2), when alcohol use may be elevated and particularly impactful on the developing brain (F. T. Crews, Braun, Hoplight, Switzer, & Knapp, 2000), and shortly after this critical period in the Project 8 sample (mean age = 23.1).

6.1. Strengths and future directions

As discussed above, the current study benefited from the use of two rich datasets, each with unique strengths. Whereas the AHB dataset consists of longitudinal data involving measures of WM previously incorporated into this line of work (digit-span recall; Finn & Hall, 2004), the Project 8 dataset includes performance on a battery of cognitive tasks that are consistent with recent conceptualizations of EF (WM updating; Miyake & Friedman, 2012). Further, both datasets contain measures tapping impulsivity and alcohol involvement, making them ideal for extending work on the interrelatedness between EF, impulsivity, and alcohol involvement.

Several characteristics of the current studies warrant discussion and suggest potential directions of future research. First, there was a notable lack of association between digit-span recall and alcohol involvement, however, this measure was still shown to moderate the association between impulsivity and alcohol involvement. This may suggest that a linear effect of WM capacity on alcohol involvement does not adequately capture this relationship, and future research should further elucidate this relationship. Second, WM capacity moderated the relationship between alcohol use and only some measures of impulsivity, most notably social deviance. This finding is consistent with prior work (Finn & Hall, 2004), however, it is not clear why associations between other facets of impulsivity and alcohol involvement are not also moderated by WM capacity. Specifically, this measure of social deviance is a combination of general and specific measures of impulsivity, and future research could disentangle whether one or both are necessary for this moderation effect.

In addition, there are important differences between participants in AHB, Project 8, and previous empirical work investigating the cognitive-motivational theory of alcoholism (Finn & Hall, 2004), which limit the generalizability of findings across these samples and to other populations. Whereas half of participants in AHB were recruited based on a familial risk for AUD, Project 8 included exclusion criteria for naïve drinkers, heavy drinkers, or a diagnosis of alcohol dependence. Other studies of WM, impulsivity, and alcohol involvement, such as those conducted by Finn and colleagues (Finn & Hall, 2004; Finn et al., 1999) include samples that more closely resemble the AHB sample (with roughly 50% of participants having a family history of an AUD). The lack of moderation effects in Project 8 may, therefore, be a consequence of decreased risk for AUD and/or decreased alcohol use, relative to AHB and other samples investigating these effects. Notably, all three samples were largely or entirely comprised of college students, however, it was noted that Wave 1 of the AHB sample is primarily comprised of individuals near the end of adolescence and the Project 8 sample is entirely comprised of individuals 21 and older. Regardless, future research investigating similar moderation effects should include samples that are more representative of the general population. The use of the TPQ may further limit the findings in the current studies, as the factor structure posited to underlie the TPQ has not replicated in some severe populations (e.g., Cannon, Clark, Leeka, & Keefe, 1993).

Finally, as noted above, future studies should consider at least two important characteristics of WM. First, research should consider that WM, as well as impulsivity, is a dynamic construct that changes over time and be designed and analyzed to reflect likely developmental change (e.g., with repeated assessments of both impulsivity and WM). Second, research should consider the multi-faceted nature of WM. In particular, it may be of interest to investigate whether the digit-span recall and spatial 2-back tasks measure common facets of WM, as both demonstrated moderation effects in the current study. The need for a better understanding of how WM relates to problematic alcohol use is highlighted by the recent use of working memory training as an effective treatment for substance use disorders (Bickel et al., 2011).

6.2. Conclusions

The current study replicated previous findings that digit-span recall moderates the association between impulsivity and alcohol involvement, while extending these findings to show that this moderation effect predicts alcohol involvement prospectively (from 18 to 22 years old). The use of digit-span recall as a measure of WM has been questioned, however, and the current study included alternative measures that reflect the construct of WM updating. It is particularly important to use multiple indicators of complex, multifaceted constructs, such as WM, which likely involve contributions of distinct lower-level components. If multiple measures of WM cannot be administered and tested, future research should speak to specific abilities being assessed.

Notably, the factor of WM updating used in the current study did not consistently moderate the relationship between impulsivity and alcohol involvement, but performance on the spatial 2-back task did yield two moderation effects across impulsivity and alcohol involvement. This lack of findings, however, may be due to the use of impulsivity measures that do not adequately capture the constructs intended. Further, given the novelty of these results, future research should attempt to replicate these findings using samples more representative of the general population.

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Contributors

Drs. Kenneth Sher and Bruce Bartholow designed the studies and wrote the protocol for the Alcohol, Health and Behavior and Project 8 studies, respectively. Mr. Jarrod Ellingson and Ms. Kimberly Fleming wrote the first draft of the manuscript and all authors contributed to and have approved the final manuscript. Mr. Ellingson, Ms. Fleming, and Mr. Alvaro Verges conducted the statistical analysis.

Conflict of interest

All other authors declare that they have no conflict of interest.

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