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Working Memory Capacity Moderates the Predictive Effects of Drug-Related Associations on Substance Use

Jerry L. Grenard,

Institute for Health Promotion and Disease Prevention Research, Keck School of Medicine,
University of Southern California, Los Angeles, CA

Susan L. Ames,

Institute for Health Promotion and Disease Prevention Research, Keck School of Medicine,
University of Southern California, Los Angeles, CA

Reinout W. Wiers,

Maastricht University, Maastricht, The Netherlands

Carolien Thush,

Maastricht University, Maastricht, The Netherlands

Steve Sussman, and

Institute for Health Promotion and Disease Prevention Research, Keck School of Medicine,
University of Southern California, Los Angeles, CA

Alan W. Stacy

Institute for Health Promotion and Disease Prevention Research, Keck School of Medicine,
University of Southern California, Los Angeles, CA

Abstract

Some theories suggest that spontaneously activated, drug-related associations in memory may have a “freer reign” in predicting drug use among individuals with lower working memory capacity. This study evaluated this hypothesis among 145 at-risk youth attending continuation high schools (CHS). This is the first study to evaluate this type of dual-process interaction in the prediction of drug use among a sample of at-risk adolescents. The CHS students completed assessments of drug-related memory associations, working memory capacity, and drug use. Control variables included age, gender, ethnicity, and acculturation. Robust multiple regression using least trimmed squares estimation indicated that there was a significant linear by linear interaction between working memory capacity as assessed with the self-ordered pointing task (SOPT) and drug-related associations (assessed with verb generation and cue-behavior association tasks) in the prediction of alcohol and cigarette use. Consistent with dual-process cognitive theories, drug-related associations in memory predicted drug use more strongly in students with lower levels of working memory capacity. These findings add to the literature implicating the influence of dual cognitive processes in adolescent risk behaviors.

Correspondence concerning this manuscript should be addressed to: Jerry L. Grenard, Institute for Prevention Research, University of Southern California, 1000 South Fremont, Unit #8, Los Angeles, California 91803, facsimile: (626) 457-4012, grenard@usc.edu.

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Keywords

Substance use; adolescents; working memory; and implicit cognition

Goal directed behavior is thought to be influenced by a range of executive cognitive functions such as inhibition, planning, and monitoring, mediated in large part by the prefrontal cortex (for review, see Royall et al., 2002). Deficits in executive cognitive functioning among adolescents have been associated with conduct problems and alcohol use (e.g., Giancola, Shoal, & Mezzich, 2001; Moss, Kirisci, Gordon, & Tarter, 1994). Further, deficits in executive functioning have been found to predate the onset of substance use disorders among adolescents and adults (Block, Bates, & Hall, 2003; Tarter et al., 2003). Despite the importance of executive functioning in the study of health behavior, dual process models of judgment and decision-making theorize that behavior is also influenced by more spontaneous cognitive processes (e.g., Kahneman, 2003). The current study extends the research on executive processes in substance use to examine how these controlled processes interact with more spontaneous cognitive processes to predict behavior.

Beginning with the work of Tiffany (1990), dual process models of addiction have proposed a distinction between at least two different types of processes. One set of processes is considered to be faster, more spontaneous, automatic, associative, or implicit. The other set of cognitive processes is more controlled, reflective, deliberate, or executive in nature. Recent research has expanded support for the view that multiple, cognitive-motivational processes play a role in substance use (e.g., Bechara & Damasio, 2002) as well as other behaviors (e.g., intuitive judgment; Kahneman, 2003). In addition, empirical support ranging from functional to neural for distinctions in cognitive processes is increasing with the availability of new methods of assessing implicit and executive processes (for review, see Wiers & Stacy, 2006b).

Within the spontaneous or implicit set of processes, drug-related associations in memory, which are often appetitive in nature, can be activated by environmental or internal stimuli without the need for deliberate recollection (cf., Kahneman, 2003). These memory associations can directly trigger contingent action tendencies such as substance use without further deliberation (Stacy, Ames, & Knowlton, 2004; Wiers et al., 2007). Research in this area has benefited from the application of assessment strategies previously developed for basic research on automatic processes in affect, memory, and decision-making (Wiers & Stacy, 2006a). Several well-researched assessment strategies for automatic processes have shown predictive validity in studies of addictive behaviors across a range of populations and for a number of drugs of abuse (for reviews, see McCusker, 2001; Wiers & Stacy, 2006b). These methods include assessments of spontaneous memory associations, used in the present study, as well as a range of reaction time methods used in other research.

In some recent dual process models, spontaneous and executive processes may interact. One specific model of executive functioning that is relevant to this interplay is the executive attention view of working memory capacity (WMC) proposed by Engle, Kane, and colleagues (e.g., Engle, 2002), which has construct validity support across psychometric and neural domains (for review, see Kane & Engle, 2002). In this model, working memory maintains information (e.g., goals and behavioral options) in an active state especially in the presence of interference. Individual differences in WMC are associated with a range of complex cognitive tasks such as reading comprehension and reasoning (Engle, 2002) and are likely to influence decisions about substance use. In a discussion of WMC and dual process theories, Barrett, Tugade, and Engle (2004) suggest that the ability to control attentional resources (i.e., WMC) can moderate the effects of automatic cognitive processes. The

automatic activation of associations by environmental cues occurs naturally among all persons, but those activated mental representations are more likely to influence behavior among individuals with lower WMC. For those higher in WMC, more top-down, goal-directed attentional resources are available to (a) suppress the influence of associative tendencies when they interfere with other active goal-states, (b) maintain conflicting goals in active memory, (c) draw on more knowledge concerning potential short vs. long-term outcomes, and (d) apply one of several cognitive processing strategies to resolve the goal conflict (see also, Stacy, Ames, & Knowlton, 2004; Wiers & Stacy, 2006a).

The primary aim of the current study is to examine the interplay of WMC and spontaneous drug-related memory associations in the prediction of substance use behaviors among adolescents at-risk of substance use. Substance-related associations in memory are expected to predict substance use more strongly for those lower in WMC compared to those higher in WMC.

Methods

Participants

Participants were recruited from four continuation high schools (CHS) in the Los Angeles area. CHS provide education for students who are unable to attend regular high schools for various reasons including conduct problems and drug use. CHS students are at higher risk of substance abuse than regular high school students (Sussman, Stacy, Dent, & Simon, 1995), which makes it important to understand drug use behaviors among these students in order to design more effective interventions. After school administrators approved the study, all students in a convenience sample of classrooms were invited to participate. Students and their parents were informed that the study concerned health behaviors and that participants might be asked about unspecified health-related behaviors that might be illegal. Students and parents were also informed that all consented participants would complete paper surveys, and that 8 participants would be selected at random from each classroom to complete computer tasks. All participating students signed assent/consent forms and the parents of students under the age of 18 provided consent according to procedures approved by the university Institutional Review Board.

Of the 404 students invited to participate, 188 agreed to participate (150 did not return the assent/consent forms and 66 declined to participate). Of those consenting, a total of 155 students completed the questionnaires and computer-based WMC assessment. Five participants were excluded due to missing data, 2 were excluded due to faulty response sets in the drug use measures, and 3 were excluded because they failed to follow instructions during the SOPT task. The analytic data set included 145 participants. The mean age of the participants was 16.7 (SD=0.74) years (see Table 1). Females comprised 33.8% of the group, and 69.7% self-reported being Latino with the other participants reporting as non-Latino White, African-American, Asian, Native American, or mixed ethnicity. In the current sample, 68.28% of participants reported using alcohol and 37.24% reported using cigarettes in the 30-days prior to the survey. Illustrating the at-risk nature of this sample, national population data showed much lower levels of use: 30.1% of 16 to 17 year olds used alcohol and 20.6% used cigarettes in the past 30 days (SAMHSA, 2006).

Measures

Self-ordered pointing task (SOPT)—A computer-based version of the SOPT (Peterson, Pihl, Higgins, & Lee, 2002) was used in the current study to assess WMC. The SOPT was developed by Petrides and Milner (1982) to measure higher level functioning among patients with frontal lobe injuries. Although originally developed to assess the executive

abilities of organization and planning, optimal SOPT performance requires high levels of WMC (Petrides, Alivisatos, Evans, & Meyer, 1993; Ross, Hanouskova, Giarla, Calhoun, & Tucker, 2007; Strauss, Sherman, & Spreen, 2006). Performance is associated with neural activity in the dorsolateral prefrontal cortex, the brain region believed to mediate controlled processing functions of working memory (Petrides et al., 1993). SOPT error scores are significantly correlated with other measures of working memory including the WAIS-III Letter-Numbering Sequencing score (Ross et al., 2007) and the matrices subtest of the WASI (Cragg & Nation, 2007), and the SOPT is uncorrelated with other executive functions such as inhibition and set shifting as measured by the Stroop and Wisconsin Card Sorting tests, respectively (Ross et al., 2007). Test-retest reliability results were good for children across a 4 month interval ($r=.76$, Archibald & Kerns, 1999) and for young adults across a 43 day interval ($r_{icc}=.82$, Ross et al., 2007). Internal consistency results have been mixed, but good values have been observed for children and young adults (Coefficient $\alpha=.88$; Cragg & Nation, 2007). The internal consistency among the participants in the current study was acceptable across the six trials (Coefficient $\alpha=.72$). The SOPT has been used successfully as a measure of working memory capacity across a wide range of topics and age groups including, for example, studies of cognitive development and aging (Cragg & Nation, 2007; Daigneault & Braun, 1993), aggression in boys (Seguin, Nagin, Assaad, & Tremblay, 2004), and development of prospective memory among children (Ward et al., 2005). A key advantage for using the SOPT in the present sample was the participants' ability to self-administer the computer-based task.¹ Each participant completed a total of 6 trials. In each trial, participants were shown a series of 12 screens with the same 12 images, but the location of the images was changed randomly across the 12 screens. Participants were instructed to use the mouse to click on a different image on each of the 12 screens in each trial. Clicking on the same image on two different screens during a single trial was an error. The SOPT score consisted of the number of selections ($6 \text{ trials} \times 12 \text{ screens} = 72$) minus the number of errors.

Drug-related associations in memory—Word association tasks assessed spontaneous, drug-related associations in memory. Several types of evidence indicate that word association is capable of measuring cognitive processes that are relatively spontaneous, automatic, or implicit (for review, see Stacy, Ames, & Grenard, 2006): (a) automatic priming occurs in word association among amnesic patients (e.g., Levy, Stark, & Squire, 2004), (b) participants do not use deliberate retrieval processes during word association tasks (Mulligan, 1998: experiment 2), (c) dissociations occur between deliberate retrieval tasks and word association providing some evidence for a distinction in cognitive processes (e.g., Goshen-Gottstein & Kempinsky, 2001). Further, word association priming occurs at the conceptual level, not just at the perceptual level (Zeelenberg, Pecher, Shiffrin, & Raaijmakers, 2003). These studies suggest that word association is capable of measuring important aspects of spontaneous associative processing systems.

Three word association tasks were used in the current study: cue-behavior, outcome-behavior, and compound cue tasks. Participants read verbal cues typed on the pages of the questionnaire and then wrote their responses next to each of the cues (e.g., Stacy, 1997). For the *cue-behavior task*, the participants were instructed to write the first word that came to mind. Cues included homographs (e.g., draft, tap) related to alcohol or other drugs and filler cues (e.g., neon, shed). In the *outcome-behavior* and the *compound cue tasks*, participants were instructed to write the first behavior that came to mind (verb generation). The cues for the outcome-behavior association task included phrases for positive outcomes of substance

¹At the time of this study, we were not aware of any other measures of WMC including span tasks that were ready to use among adolescents as self-administered, computer-based tasks.

use (e.g., feeling relaxed, being sociable) and filler cues (e.g., showing respect). The compound cue task combined locations and outcome cues in a single phrase (e.g., friend's house - feeling good). Two independent judges coded each response (1=drug related or 0=not drug related), with the proportion of agreement being 98 to 99%. A composite score was created from the three tasks for each substance with a higher score indicative of stronger drug-related associations.

Control variables—The covariates age, gender, ethnicity, school attended, and acculturation (Marin et al., 1987) were measured as potential confounders of the relationship between the dependent variables and one or both of the independent variables of interest in the interaction. The dependent variables, alcohol and cigarette use, have been shown to be associated with all of the covariates including age and gender (SAMHSA, 2006), clustering of participants in schools (cf., Murray & Short, 1997), ethnicity (SAMHSA, 2006), and acculturation (e.g., Borges et al., 2006; Guilamo-Ramos, Jaccard, Johansson, & Tunisi, 2004). The independent variables may also be associated with the covariates. WMC has been associated with age (Brown & Tapert, 2004), and drug-related associations might have some small association with the other covariates. The English language-based word association measure of drug-related associations may be influenced by behavior and language usage associated with cultural experiences that differ across ethnicities, levels of acculturation, and possibly across school level micro-cultures (measured as school attended) related to drug use. Although previous studies have not found an association between drug-related associations and ethnicity or acculturation (e.g., Stacy, 1997; Stacy, Ames, Sussman, & Dent, 1996), we have included these covariates and the school attended in the current models as a precaution.

Frequency of drug use—Self-reports of the frequency of drug use for two time periods were collected for alcohol and cigarettes (for reliability and validity, see Graham et al., 1984; Stacy, 1997). Students were asked how many times they have used each drug in their lifetime and in the past 30-days, and they responded on an 11-point rating scale that ranged from “never used” to “91–100+ times.” Frequency of drug use indices were created by summing the two frequency responses for alcohol (coefficient $\alpha=.60$) and cigarettes (coefficient $\alpha=.83$).

Procedure

University staff members set up a portable computer lab and collected data in a room reserved at each school. The computer lab included 8 IBM ThinkPad laptop computers with 15-inch LCD color monitors. A standard 2-button mouse was connected to the laptops. On the day of data collection, 8 students in a classroom were randomly selected from among those who had consented. The 8 students were escorted to the temporary computer lab to complete both paper and computer-based assessments. A paper survey only was administered to those students who had consented but were not selected to complete the computer tasks.

The assessments were administered in a set order: (1) paper-and-pencil word association tasks (2) computer-based SOPT, and (3) paper-and-pencil questionnaire for drug use and covariates. Instructions for the SOPT were displayed on the computer screen and read out loud by the data collectors (see measures section for task details). After completing the assessments, the students were thanked for their participation and they returned to their normal classrooms.

Data Analysis

Testing the interaction models was completed in two steps (Aiken & West, 1991; Cohen, Cohen, West, & Aiken, 2003). First, the data were tested for quadratic effects using a global comparison of the effects sizes (R^2 values) between models with and without quadratic terms. Covariates included age, gender, ethnicity, acculturation, and the school attended. The interaction variables included WMC and drug-related associations, and these variables were centered on their means before generating higher order terms. Models were individually tested for the frequency of alcohol or cigarette use as the dependent variables. The second step of model testing involved evaluation of linear by linear models of the interactions using multiple regression analyses.

Results

Descriptive statistics for the variables are shown in Table one (see discussion in the participant section). Note that WMC data were successfully collected from groups of students using the mobile computer lab.

The global test comparing a full quadratic model to a linear by linear interaction model was non-significant for alcohol use, $F(4,134) = 0.21$, $p = .93$, and for cigarette use, $F(4,134) = 2.18$, $p = .07$. Based upon these results, there were no quadratic effects and all subsequent analyses were conducted on the linear by linear interaction model.

The interaction terms were non-significant in the regression model for alcohol use ($p > .05$) and for cigarette use ($p > .05$) using ordinary least squares (OLS) estimation methods. The residuals for the interaction models were not normally distributed, however, violating one of the assumptions for OLS estimation (Kolmogorov-Smirnov $p < .01$). For non-normal residuals, Cohen et al. (2003) recommended using robust estimation methods such as M estimation and Least Trimmed Squares (LTS) estimation. Both robust procedures produced statistically significant interaction parameters for alcohol ($p < 0.05$) and cigarette use ($p < 0.05$) models. The parameters from the robust LTS estimation are described below.

The model parameters for alcohol use are shown in Table 2. Gender, age, acculturation, ethnicity, and school attended were not significant predictors of alcohol use (all $p > .05$). The SOPT score ($p < .01$), associative memory ($p < .01$), and the interaction term ($p = 0.02$) were significant predictors of alcohol use. Note that main, additive effects for WMC and associative memory may not be inferred from the first order terms in the regression model when the interaction term is statistically significant and the first order effects are conditional on the interaction (Cohen et al., 2003). The model accounted for 36.6% of the variance, and the interaction term accounted for 0.40% of the variance. Figure 1 shows the relationship between the self-reported frequency of alcohol use as a function of alcohol-related associations (x-axis) and SOPT score, which was plotted for three values including the mean and the mean plus or minus one standard deviation. The simple slopes increased with decreasing SOPT scores showing that alcohol-related memory associations were a better predictor of alcohol use among those lower in WMC than among those higher in WMC.

The cigarette model results were slightly different from those found in the alcohol model. First, the covariates school attended ($p < .05$) and gender ($p < .01$) were significant in the cigarette model but not the alcohol model. Second, the first order SOPT term was not a significant predictor in the cigarette model whereas it was in the alcohol model. The interaction term, however, was significant in both the full alcohol and cigarette models. The cigarette model explained 44.5% of the variance overall, and the interaction term explained 3.2% of the variance. The graph of the interaction effect for cigarette use was similar to the graph of the alcohol model in one key aspect. The simple slopes increased with decreasing

SOPT scores, revealing that cigarette-related associations were a better predictor of cigarette use among those lower in WMC than among those higher in WMC.

Discussion

This is the first study to evaluate the interaction between working memory and drug-relevant memory associations in the prediction of substance use. As anticipated, these data from at-risk adolescents reveal that drug-related associations are stronger predictors of alcohol and cigarette use among those with lower WMC than among those with higher WMC. The models explain a sizable amount of the variance: 37% for alcohol use and 44% for cigarette use. However, the proportion of variance explained by the interaction terms is small as often expected in similar field research incorporating interaction effects (McClelland & Judd, 1993). Nevertheless, the interaction findings in the current study are consistent with dual process theories and the hypothesis that higher WMC moderates the effects of spontaneous drug-related associations (e.g., Barrett et al., 2004; Stacy et al., 2004). Further, virtually identical results have been recently replicated in a related study among at-risk adolescents in The Netherlands, in which a very different reaction time measure of associations was used (Thush et al., 2007).

The formation and strengthening of drug-relevant memory associations may result from direct drug use experiences or from vicarious learning, and these associations appear to influence behavior spontaneously with or without conscious deliberation (Barrett et al., 2004; Wiers & Stacy, 2006b). Higher WMC has the potential to be protective through one or more mechanisms: inhibit acting out associative responses, hold and consider conflicting goals in active memory, retrieve relevant information from long-term memory, and apply one or more cognitive processing strategies to successfully resolve conflicting goals (Barrett et al., 2004).

Although further replication of the present findings is needed, the results of this study have important implications for the design of prevention program components. It may be possible to tailor program components (e.g., training of working memory; see Olesen, Westerberg, & Klingberg, 2004) for individuals with lower WMC to improve attentional resources in situations in which strong implicit associations are activated by drug use cues. A second approach might be to intervene at the level of the spontaneous drug-related associations (Wiers et al., 2006) by creating new associations, for example, in long-term memory between certain drug abuse prevention materials and contexts associated with drug use. Then program materials are more likely to be spontaneously activated in memory when an individual is confronted with strong drug-use cues (Stacy, Ames, & Knowlton, 2004).

There are several limitations in this study. First, the cross-sectional data limit causal inference for the direction of the interactions in the current models. Second, generalizations of the findings are limited to similar groups of at-risk adolescents. Third, although it makes theoretical sense, we cannot confidently conclude that WMC specifically is moderating the influence of drug associations on drug use because the SOPT assesses other executive functions to some minor degree, such as planning and organization in addition to WMC (Ross et al., 2007). Future research using multiple measures of WMC and measures of other executive functions could clarify this issue. Nevertheless, this study provides important insights into the interaction of deliberative and automatic cognitive processes in adolescent risk behaviors.

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References

- Aiken, L.S.; West, S.G. Multiple regression: Testing and interpreting interactions. Thousand Oaks, CA: Sage Publications; 1991.
- Archibald SJ, Kerns KA. Identification and description of new tests of executive functioning in children. *Child Neuropsychology*. 1999; 5(2):115–129.
- Barrett LF, Tugade MM, Engle RW. Individual differences in working memory capacity and dual-process theories of the mind. *Psychological Bulletin*. 2004; 130(4):553–573. [PubMed: 15250813]
- Bechara A, Damasio H. Decision-making and addiction (part I): Impaired activation of somatic states in substance dependent individuals when pondering decisions with negative future consequences. *Neuropsychologia*. 2002; 40(10):1675–1689. [PubMed: 11992656]
- Block RI, Bates ME, Hall JA. Relation of premorbid cognitive abilities to substance users' problems at treatment intake and improvements with substance abuse treatment and case management. *American Journal of Drug & Alcohol Abuse*. 2003; 29(3):515–538. [PubMed: 14510038]
- Borges G, Medina-Mora ME, Lown A, Ye Y, Robertson M, Cherpitel C, et al. Alcohol Use Disorders in National Samples of Mexicans and Mexican-Americans: The Mexican National Addiction Survey and the U.S. National Alcohol Survey. *Hispanic Journal of Behavioral Sciences*. 2006; 28(3):425–449.
- Brown SA, Tapert SF. Adolescence and the trajectory of alcohol use: Basic to clinical studies. *Annals of the New York Academy of Sciences*. 2004; 1021:234–244. [PubMed: 15251893]
- Cragg L, Nation K. Self-ordered pointing as a test of working memory in typically developing children. *Memory*. 2007; 15(5):526–535. [PubMed: 17613795]
- Cohen, J.A.; Cohen, P.A.; West, S.G.A.; Aiken, L.S.A. Applied multiple regression - correlation analysis for the behavioral sciences. 3. Mahwah: Lawrence Erlbaum Associates; 2003.
- Daigneault S, Braun CM. Working memory and the Self-Ordered Pointing Task: Further evidence of early prefrontal decline in normal aging. *Journal of Clinical and Experimental Neuropsychology*. 1993; 15(6):881–895. [PubMed: 8120125]
- Engle RW. Working memory capacity as executive attention. *Current Directions in Psychological Science*. 2002; 11(1):19–23.
- Finn PR, Justus A, Mazas C, Steinmetz JE. Working memory, executive processes and the effects of alcohol on Go/No-Go learning: testing a model of behavioral regulation and impulsivity. *Psychopharmacology*. 1999; 146(4):465–472. [PubMed: 10550497]
- Giancola PR, Shoal GD, Mezzich AC. Constructive thinking, executive functioning, antisocial behavior, and drug use involvement in adolescent females with a substance use disorder. *Experimental & Clinical Psychopharmacology*. 2001; 9(2):215–227. [PubMed: 11518098]
- Goshen-Gottstein Y, Kempinsky H. Probing memory with conceptual cues at multiple retention intervals: A comparison of forgetting rates on implicit and explicit tests. *Psychonomic Bulletin & Review*. 2001; 8(1):139–146. [PubMed: 11340859]
- Graham JW, Flay BR, Johnson CA, Hansen WB, Grossman L, Sobel JL. Reliability of self-report measures of drug use in prevention research: Evaluation of the project SMART questionnaire via the test-retest reliability matrix. *Journal of Drug Education*. 1984; 14:175–193. [PubMed: 6536737]
- Guilamo-Ramos V, Jaccard J, Johansson M, Tunisi R. Binge Drinking Among Latino Youth: Role of Acculturation-Related Variables. *Psychology of Addictive Behaviors*. 2004; 18(2):135–142. [PubMed: 15238055]
- Jacobsen LK, Krystal JH, Mencl WE, Westerveld M, Frost SJ, Pugh KR. Effects of smoking and smoking abstinence on cognition in adolescent tobacco smokers. *Biological Psychiatry*. 2005; 57(1):56–66. [PubMed: 15607301]
- Kahneman D. A perspective on judgment and choice: Mapping bounded rationality. *American Psychologist*. 2003; 58(9):697–720. [PubMed: 14584987]

- Kane MJ, Engle RW. The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*. 2002; 9(4):637–671. [PubMed: 12613671]
- Levy DA, Stark CEL, Squire LR. Intact conceptual priming in the absence of declarative memory. *Psychological Science*. 2004; 15(10):680–686. [PubMed: 15447639]
- Marin G, Sabogal F, Marin BV, Otero-Sabogal R, Perez-Stable EJ. Development of a short acculturation scale for Hispanics. *Hispanic Journal of Behavioral Sciences Special Acculturation research*. 1987; 9(2):183–205.
- McClelland GH, Judd CM. Statistical difficulties of detecting interactions and moderator effects. *Psychological Bulletin*. 1993; 114(2):376–390. [PubMed: 8416037]
- McCusker CG. Cognitive biases and addiction: An evolution in theory and method. *Addiction*. 2001; 96(1):47–56. [PubMed: 11177519]
- Moss HB, Kirisci L, Gordon HW, Tarter RE. A neuropsychologic profile of adolescent alcoholics. *Alcoholism: Clinical and Experimental Research*. 1994; 18(1):159–163.
- Mulligan NW. The role of attention during encoding in implicit and explicit memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*. 1998; 24(1):27–47.
- Murray DM, Short BJ. Intraclass correlation among measures related to tobacco use by adolescents: Estimates, correlates and applications in intervention studies. *Addictive Behaviors*. 1997; 22(1):1–12. [PubMed: 9022867]
- Olesen PJ, Westerberg H, Klingberg T. Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience*. 2004; 7(1):75–79.
- Peterson, JB.; Pihl, RO.; Higgins, D.; Lee, A. *NeuroCognitive Battery (Version 2.0)*. Deerfield Beach; FL: 2002.
- Petrides M, Alivisatos B, Evans AC, Meyer E. Dissociation of human mid- dorsolateral from posterior dorsolateral frontal cortex in memory processing. *Proceedings of the National Academy of Sciences of the United States of America*. 1993; 90(3):873–877. [PubMed: 8430100]
- Petrides M, Milner B. Deficits on subject-ordered tasks after frontal- and temporal-lobe lesions in man. *Neuropsychologia*. 1982; 20(3):249–262. [PubMed: 7121793]
- Ross TP, Hanouskova E, Giarla K, Calhoun E, Tucker M. The reliability and validity of the self-ordered pointing task. *Archives of Clinical Neuropsychology*. 2007; 22(4):449–458. [PubMed: 17321716]
- Royall DR, Lauterbach EC, Cummings JL, Reeve A, Rummans TA, Kaufer DI, et al. Executive control function: A review of its promise and challenges for clinical research: A report from the committee on research of the American Neuropsychiatric Association. *Journal of Neuropsychiatry and Clinical Neurosciences*. 2002; 14(4):377–405. [PubMed: 12426407]
- Sacco KA, Bannon KL, George TP. Nicotinic receptor mechanisms and cognition in normal states and neuropsychiatric disorders. *Journal of Psychopharmacology*. 2004; 18(4):457–474. [PubMed: 15582913]
- SAMHSA. Office of Applied Studies, DSDUH Series H-30, DHHS Publication No. SMA 06–4194. Rockville, MD: Substance Abuse and Mental Health Services Administration; 2006. Results from the 2005 national survey on drug use and health: National Findings.
- Seguin JR, Nagin D, Assaad JM, Tremblay RE. Cognitive-neuropsychological function in chronic physical aggression and hyperactivity. *Journal of Abnormal Psychology*. 2004; 113(4):603–613. [PubMed: 15535792]
- Stacy AW. Memory activation and expectancy as prospective predictors of alcohol and marijuana use. *Journal of Abnormal Psychology*. 1997; 106(1):61–73. [PubMed: 9103718]
- Stacy, AW.; Ames, SL.; Grenard, JL. *Handbook on implicit cognition and addiction*. Thousand Oaks, CA: Sage; 2006. Word association tests of associative memory and implicit processes: Theoretical and assessment issues.
- Stacy AW, Ames SL, Knowlton BJ. Neurologically plausible distinctions in cognition relevant to drug use etiology and prevention. *Substance Use & Misuse*. 2004; 39(10–12):1571–1623. [PubMed: 15587946]
- Stacy AW, Ames SL, Sussman S, Dent CW. Implicit cognition in adolescent drug use. *Psychology of Addictive Behaviors*. 1996; 10(3):190–203.

- Strauss, E.; Sherman, EMS.; Spreen, O. A compendium of neuropsychological tests: Administration, norms, and commentary. 3. New York, NY, US: Oxford University Press; 2006.
- Sussman S, Stacy AW, Dent CW, Simon TR. Continuation high schools: Youth at risk for drug abuse. *Journal of Drug Education*. 1995; 25(3):191–209. [PubMed: 7500223]
- Tarter RE, Kirisci L, Mezzich A, Cornelius JR, Pajer K, Vanyukov M, et al. Neurobehavioral disinhibition in childhood predicts early age at onset of substance use disorder. *American Journal of Psychiatry*. 2003; 160(6):1078–1085. [PubMed: 12777265]
- Thush, C.; Wiers, RW.; Ames, SL.; Grenard, JL.; Sussman, S.; Stacy, AW. Interactions between implicit and explicit cognition and working memory capacity in the prediction of alcohol use in at-risk adolescents. 2007. Manuscript submitted for publication
- Tiffany ST. A cognitive model of drug urges and drug-use behavior: Role of automatic and nonautomatic processes. *Psychological Review*. 1990; 97(2):147–168. [PubMed: 2186423]
- Ward H, Shum D, McKinlay L, Baker-Tweney S, Wallace G. Development of prospective memory: Tasks based on the prefrontal-lobe model. *Child Neuropsychology*. 2005; 11(6):527–549. [PubMed: 16306026]
- Wiers RW, Bartholow BD, van den Wildenberg E, Thush C, Engels RCME, Sher KJ, et al. Automatic and controlled processes and the development of addictive behaviors in adolescents: A review and a model. *Pharmacology, Biochemistry and Behavior Special Issue: Adolescents, drug abuse and metal disorders*. 2007; 86(2):263–283.
- Wiers RW, Cox WM, Field M, Fadardi JS, Palfai TP, Schoenmakers T, et al. The search for new ways to change implicit alcohol-related cognitions in heavy drinkers. *Alcoholism: Clinical and Experimental Research*. 2006; 30(2):320–331.
- Wiers RW, Gunning WB, Sergeant JA. Is a mild deficit in executive functions in boys related to childhood ADHD or to parental multigenerational alcoholism? *Journal of Abnormal Child Psychology*. 1998; 26(6):415–430. [PubMed: 9915649]
- Wiers RW, Stacy AW. Implicit cognition and addiction. *Current Directions in Psychological Science*. 2006a; 15(6):292–296.
- Wiers, RW.; Stacy, AW., editors. *Handbook of implicit cognition and addiction*. Thousand Oaks, CA: Sage; 2006b.
- Zeelenberg R, Pecher D, Shiffrin RM, Raaijmakers JGW. Semantic context effects and priming in word association. *Psychonomic Bulletin & Review*. 2003; 10(3):653–660. [PubMed: 14620360]

Figure 1.

Plot of the interactions between working memory capacity (WMC) and drug-related memory associations in the prediction of (a) the frequency of alcohol use and (b) the frequency of cigarette use. SOPT score is plotted at the mean (Mean SOPT Score), the mean plus one standard deviation (Higher SOPT Score), and the mean minus one standard deviation (Lower SOPT Score). SOPT = Self Ordered Pointing Task.

Table 1

Descriptive Statistics

Item	Value M (SD)
Age	16.71 (0.74)
Grade	11.59 (0.63)
Gender: N (%)	
Male	96 (66.21%)
Female	49 (33.70%)
Self-reported ethnicity: N (%)	
Latino	101 (69.66%)
Mixed	13 (8.97%)
White	11 (7.59%)
Asian	10 (6.90%)
Black	5 (3.45%)
Other	5 (3.45%)
Language acculturation ¹	4.05 (0.84)
SOPT score	54.95 (6.09)
Alcohol-related association score	1.24 (1.82)
Tobacco-related association score	0.59 (1.68)
Frequency of substance use ²	
Alcohol use in lifetime	5.11 (3.53)
Alcohol use last month	2.49 (2.28)
Tobacco use in lifetime	3.94 (3.64)
Tobacco use last month	2.44 (2.87)

Notes: SOPT = Self-Ordered Pointing Task.

¹Language acculturation: 4=English more than another language; 5=only English.

²Frequency of substance use: 2=1–10 times; 3=11–20 times; 4=21–30 times; 5=31–40 times.

Table 2**Regression Models Using Robust Least Trimmed Squares Estimation**

Variable	<i>B</i>	χ^2	<i>p</i>	Cumulative R^2
Alcohol-use model				
Intercept	3.204	0.16	.69	
School 2	1.557	1.49	.22	
School 3	1.116	1.62	.22	
School 4	1.997	2.49	.11	
Age	0.120	0.06	.80	
Gender (female=1; male=0)	−0.743	0.97	.32	
Ethnicity (Latino=1; other=0)	1.892	3.67	.06	↓
Language acculturation	−0.039	0.01	.93	.132
SOPT score (X)	0.170	8.84	<.01	.272
Alcohol associations (Z)	0.858	18.44	<.01	.362
Interaction (XZ)	−0.080	5.50	.02	.366
Cigarette-use model				
Intercept	2.732	0.47	.50	
School 2	1.165	3.24	.07	
School 3	0.901	5.30	.02	
School 4	1.787	6.80	.01	↓
Age	0.018	0.01	.94	
Gender (female=1; male=0)	−1.144	9.82	<.01	
Ethnicity (Latino=1; other=0)	0.947	3.45	.06	
Language acculturation	0.323	2.15	.14	.169
SOPT score (X)	0.008	0.08	.77	.194
Cigarette association (Z)	1.238	154.33	<.01	.413
Interaction (XZ)	−0.033	5.58	.02	.445

Notes. Continuous predictor variables were centered on their means to obtain the (non-standardized) parameter estimates (*B*); SOPT = Self-Ordered Pointing Task.