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Adolescents at Risk for Drug Abuse: A 3-Year Dual Process Analysis

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Abstract

Aims—To test longitudinal additive and synergistic dual process models in youth at documented risk for drug use. The specific dual process approach examined suggests that engaging in drug use behaviors results from a dynamic interplay between automatically-activated associative memory processes and executive reflective/control processes.

Design—This 3-year, three-wave population-based prospective study used mobile computer-based assessments.

Setting—Self-directed computer assessments were completed in school settings in the Los Angeles metropolitan area, California, USA.

Participants—725 at-risk adolescents (44% female) in continuation high schools were recruited during 9th grade (age at recruitment, 14 to 16).

Measurements—Key outcome measures included past year alcohol, marijuana and cigarette use at each assessment. Predictors included working memory capacity (WMC), associative memory, the interaction term WMC by associative memory, sex, age, ethnicity, and acculturation.

Findings—A significant cross-sectional interaction revealed tobacco-relevant associations were *weaker* predictors of cigarette use among males with *higher* WMC than among those with lower WMC ($p<0.004$). Alternatively, drug-relevant associations were stronger predictors of past year alcohol ($p<0.001$) and marijuana use ($p=0.02$) among females with higher WMC than among those with lower WMC. Longitudinal analyses revealed no significant interactions after adjusting for predictive effects of previous drug use. With respect to WMC, females with higher WMC were less likely to use marijuana at two-year follow-up ($p=0.03$). First-order effects of drug-related associations prospectively predicted greater alcohol and marijuana use in males at one and two-year follow up ($p\leq0.03$), and greater past year alcohol and marijuana use in females at one-year follow up ($p\leq0.03$).

Conclusions—Drug-relevant memory associations play a key role in drug use behavior in at-risk youth.

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Keywords

implicit associations; working memory; dual processes; drug use; adolescents; habit; longitudinal

Introduction

Although some adolescent drug use rates are declining (1), drug use rates among particular at-risk youth remain quite high. For instance, youth enrolled in Continuation High Schools (CHS) in California report more drug use than youth attending regular high schools and are therefore considered high-risk for substance abuse (2,3). Given the distribution of use in the CHS population, understanding predictors of use is clearly important. Drug use remains above the national norm in this population, making intensive epidemiologic study critical to understand why some youth are more likely to develop and perpetuate drug use while others are relatively protected. The present study investigated longitudinal additive and synergistic dual process models in youth at documented risk for drug abuse to advance understanding of individual differences affecting drug use behavior.

Dual process approaches to understanding addictive behaviors have been advanced through research on implicit associative processes and cognitive control moderators of these processes. These approaches have been motivated by findings that span diverse disciplines and research areas. Fundamental distinctions in processes or systems have been well documented in decision theory (4), memory (5,6), basic social cognition (7), and neuroscience (8–12). However, incorporation of these distinctions is relatively rare in longitudinal research on at-risk adolescents.

The dual process approach addressed in this study suggests that decisions to engage in drug use behaviors result from a dynamic interplay between implicit/spontaneous associative processes and executive reflective/control processes (13–16). Associative processes can operate non-reflectively and spontaneously when associations in memory are sufficiently strong. Experience with appetitive behaviors related to natural rewards or neural mimicry of those rewards (such as reinforcing effects of drugs) is likely to have an especially pronounced, or rapid, effect on the formation of spontaneous associations. This process results in neurobiological changes that affect subsequent behavior (17,18). Although strong associations linked to a behavior may bias a behavioral response, this effect may be modulated to some extent by executive control processes. Indeed, executive control functions known to show marked individual variability (19,20) may provide one explanation why spontaneous or automatically activated associations in cognition are not always translated into performance of a behavior. For example, when an individual faces a relevant situation (e.g., a party with drugs), risky cognitions (spontaneous anticipation of pleasure from use of a drug) may be triggered by cues and have a potential influence, but control functions can potentially promote countervailing mechanisms that reduce effects of risky tendencies through deliberation or more adaptive and flexible thought. In simple terms, people do not always act on spontaneous thoughts or impulses but are often capable of putting them out of mind or deciding on an alternative stream of thought or behavior.

To evaluate this process, the specific function investigated in this study is working memory capacity (19), a function with a strong neural basis and distinct neural system supported by evidence from divergent lines of research. Working memory is linked to the dorsolateral prefrontal cortex and related circuits (19), and is a likely candidate for an adaptive executive function that facilitates self-regulation. Good working memory ability helps individuals keep competing considerations “online” (19), even when faced with other demands on cognitive resources. Without good working memory, multiple considerations are not as likely to be kept active or “on mind” for decisions, so that explicit memory retrieval is less effective (21–23), and therefore a smaller set of learned effects (only the most spontaneously activated ones) is available to influence behavior. Thus, working memory is hypothesized to show a buffer (protective) interaction pattern.

Dual-process synergistic effects (as well as first-order or direct effects) could be especially important for explaining why some youth intensify their drug use or transition to particularly harmful drugs, while others are relatively protected. Through better working memory, some adolescents should be able to keep multiple considerations on mind rather than just the most salient ones and thus more effectively gauge whether to act on spontaneously activated associations promoting drug use. Harmful levels of drug use may then become less likely. Drug use may also be substantially reduced if spontaneous pro-drug associations are low, requiring less of a need for countervailing influences or protection. The form of this interaction has been supported in several studies on addictive behaviors (24–28).

Consistent with previous cross-sectional analyses (29,30), the following hypotheses were tested: 1) It was expected that spontaneous drug-related memory associations would more strongly predict drug use over time among adolescents with lower levels of working memory capacity (WMC). Although not hypothesized, sex differences in pattern of prediction were investigated to evaluate whether results replicate across gender. 2) It was also expected that stronger drug-relevant implicit associations would independently predict greater drug use behavior over time (a first-order effect) consistent with support in other research on drug use (for meta-analysis, see 31); and 3) A possible first-order effect of working memory was investigated as a primary additive comparison of executive control processes; specifically, that poorer working memory would predict greater drug use behavior.

Methods

Design

To test longitudinal additive and synergistic dual process models in youth at documented risk for drug use, this population-based study applied laboratory-based constructs and methods utilizing mobile computer-based assessments in school settings across three waves over 3 years. An additive dual-process model suggests that implicit memory associations and executive control functions show some independent predictive effects. Alternatively, a synergistic model is suggested by an interplay between implicit associative and executive control processes.

Participants

Participants were 725 continuation high school (CHS) students recruited at baseline from classrooms in 37 CHSs randomly selected from over 80 available in southern California not receiving drug prevention programming. The sample size was determined to be sufficient to provide stability in parameter estimation and is based on power analysis for structural equation modeling (32–34). Forty-four percent were female; mean age at baseline was 16.62 years, with the majority reporting Hispanic ethnicity (see Table 1). Youth are enrolled in CHSs for various reasons, including attendance difficulties, difficulty achieving academic credits, conduct problems, and substance use. CHS youth also report more drug use than students attending regular high schools and are therefore considered high risk for substance abuse (2,3). At the time of recruitment, all 9th grade students (age range 14 to 16) attending selected classes were invited to participate. They were assessed across three waves, each separated by 1 year. Wave 1 assessment occurred from May 2010–May 2011. Fifty-nine percent of the 725 completed the two-year follow up at Wave 3 of the study. All participants received the same assessments.

Procedure

Written assent was obtained from students and written or verbal active consent from parents. Participants were informed that the study was completely confidential and voluntary. Participants received monetary incentives in the form of movie tickets at Wave 1 and 2, and a $50 gift card at Wave 3. Reminders to take the follow-up assessments were provided by mail, email, text messages, and phone calls.

Baseline data collection took place during regular school hours with the use of a mobile computer lab. Consented participants completed computer-based assessments, requiring ~2 hours to complete. Items were ordered such that scales containing direct questioning about drugs and related confounders appeared during the later portion of the assessment, with measures of spontaneous cognition and neural function during the first half. Participants were tested in small groups and were isolated from one another and monitored, as in our previous field studies. Computerized assessments have been used successfully in problematic populations in previous research (2,24,35,36).

Follow-up assessments used both internet-based data collection and telephone surveys. In all instances, consented participants' confidentiality was ensured. No names appeared on any of the computerized instruments or anywhere on the Internet server.

Measures

Assessments of drug use—Drug use was assessed with previously evaluated measures of frequency of use (37,38). The reliability and validity of these drug-use measures have been demonstrated in previous work (39). Frequency measures included assessment of cigarettes, alcohol, marijuana and other drugs (e.g., opiates, prescription use, etc.) For each drug outcome, participants were asked, "*About how many times have you used the drug below in the past year*" (40,41). The frequency response options began with 1 (never used) and increased in intervals of 10 (e.g., 2=1–10 times, 3 =11–20 times, 4=21–30 times), with the last category being 11 (91 or more times).

Indirect tests of word association provide a class of indirect assessment of associations in memory (42–44). The present study used a series of word production trials with verb generation instructions for all items (38,44): 1. *Outcome-behavior association test (OBAT)*. The verb generation instructions asked respondents to "*Write the 1st behavior or activity that immediately pops to mind*" to an affective outcome (e.g*., feeling good*:_____). 2. *Cue-association test (CAT)*. Using the same instructions, participants respond to a situation or word cue (e.g., *Friday night*:_____). 3. *Compound cues*. These trials provide a combination of a situation/location and affective outcome as a cue (e.g., *my bedroom, feeling good*:_____). 4. *Neutral associations.* These trials used words and phrases not expected to yield risky associates (e.g., *Thursday morning. _____)* but were used to reduce response chaining and priming effects and to assess whether neutral prompts yielded any target responses. Cues were presented in randomized order to each respondent with neutral cues interspersed among risk-related cues. Stimuli came from frequency norms generated in our previous research. Validated self-coding, computerized procedures (45,46); also see (47,48) resulted in binary scores (0/1) for a set of risky associations (e.g., alcohol use) that were summed to yield indexes of associative strength in memory, range 0 to 18, for each drug outcome (38,49). Word association tests have shown stable test-retest reliability with correlations ranging from .54 to .83 over 1 to 6 month intervals (50,51). Additionally, indicators of associations from these tests form a common factor with sufficient internal consistency and good predictive utility in drug use research (2,30,48).

Working Memory Capacity (WMC) was assessed with the automated Operation Span Task (52), which has been validated in cognitive science laboratories (53–55) with alpha=.78 and test-retest reliability r=.83. The task measures one's capacity to learn and maintain information in an active state during interference and tests the ability to control one's attention (19,54). Participants remember a series of 2 to 5 letters (each letter is presented 3 times) sequentially on a computer monitor. Between letters, participants solve simple math problems and indicate if an answer to a problem is true or false (e.g., 8/2+6=10). Math problems serve as distracters requiring control of attention while maintaining letter sequences in short-term memory. A larger number of letters recalled in proper sequence is indicative of higher WM capacity (summed score range 0 – 42).

Control variables—Covariates included in all analyses were age, sex, ethnicity, and acculturation. Acculturation was assessed with items adapted from a previously validated scale of acculturation originally developed for Latinos and Whites (56). The scale measures English language use as a proxy for acculturation (38). The internal consistency reliability of the modified scale is very good (alpha = .93), and each subscale loads strongly on a common factor (38). The scale items address social relations, general language use, media preference, and identity issues (56). A sum of four items (item range 1–5) was used to assess level of acculturation, with lower scores indicative of greater acculturation.

Analytic Procedure

Preliminary data analyses involved descriptive statistics and analysis of statistical assumptions. In all subsequent analyses, the first-order predictors were: (1) spontaneous associations in memory generated on word association tests (WAT) for a specific behavior

(i.e. alcohol, marijuana or cigarette use), and (2) working memory capacity assessed with the Automated Operation Span Task (OSPAN) (52). Analyses of baseline data to obtain an estimate of intra-class correlations (ICC) considering the nested nature of the data revealed ICCs to be relatively low (0.012 for past-year use of marijuana, 0.015 for alcohol, and 0.027 for cigarettes). Here the ICC is an index of the degree of variability (or common behavior) within a school compared to the variability across schools. According to the ICC estimates and recommendations from the related literature (57), the potential risk of Type I error inflation in our analyses would be reasonably minimal and, therefore, inclusion of school random effects was not essential. Preliminary analyses revealed significant sex interactions on effects of working memory and memory associations on past-year use of alcohol, cigarettes and marijuana, as well as sex differences on neurocognitive characteristics (e.g. OSPAN) and behavioral outcomes (i.e. use of alcohol, marijuana and cigarettes in the past year). Therefore, multiple-group structural equation modeling (SEM) was used and sex-stratified results are presented.

First, measurement models for the latent constructs of the first-order predictors were constructed. Next, latent variable models were estimated to examine main and additive effects as well as interactions between the WAT and WMC. An “unconstrained” latent interaction approach of Marsh et al. (58,59) was used in the present analyses. This approach uses product terms (WAT X WMC) as multiple indicators of a latent factor, allows for more accurate estimates of the relationships among variables, and helps adjust for measurement error compared with alternative strategies (32, 60). Further, this latent interaction approach has been found to be among the most powerful among other alternatives (61). Although moderated regression is frequently used, it can sometimes underestimate interaction effects because of its reliance on a single-indicator construct used as the product (interaction) term.

Cross-sectional analyses with Wave 1 data were conducted first to evaluate baseline first-order and interaction effects of the latent constructs on each type of behavioral outcome. Next, analyses of longitudinal data were conducted to prospectively examine both types of effects on behavioral outcomes from Wave 1 to Wave 2 and from Wave 1 to Wave 3, separately. Covariates of age, acculturation, and ethnicity were included in all models, and additional control of Wave 1 behavioral outcomes was implemented in prospective analyses. Mplus software version 7 was used in all analyses (62).

Several goodness of fit indices were used to evaluate model fit (63–65). Indices included, (1) χ^2 statistic, which is non-significant ($p>0.05$) when the model is a good fit; 2) values for the comparative fit index (CFI) greater than .90 or .95 are indicative of an adequate or good fit to the data; and 3) the root mean square error of approximation (RMSEA) (66), a population-based index of fit, measures the amount of error in the model. The RMSEA for a model with good fit should ideally be <0.05, though a fit of < 0.08 is acceptable (60, 62, 67,68).

Separate Spontaneous Drug Use Association factors were conceptualized as latent constructs with 3 parcels comprised of compound cues, cue behavior associations, and outcome-behavior association items for alcohol, tobacco, and marijuana. Cues were selected that formed a reliable scale on a single dimension using a unidimensional item response theory

model (48,69) and then items were randomly assigned to 1 of 3 parcels (sum of 3 randomly selected items formed each parcel). Since applying random methods to a multidimensional set of items may lead to biased estimates of parameters, unidimensional item response theory was utilized to examine the dimensionality of the association item set. Results indicated that the item sets were sufficiently unidimensional. Random assignment of the items to parcels was identical across participants.

The Working Memory Capacity factor (WMC) was conceptualized as a latent construct with repeated trials as indicators. Indicators consisted of sums of multiple items or parcel scores. The parcel method was used to combine trials to create more reliable and valid indicators for the latent constructs (70), and the latent constructs have previously been found to form homogeneous factors (29,47,48). Individual trials were randomly assigned to one of three parcels. This procedure helps limit chance model misfit likely when using an alternative method of assigning numerous homogenous trials as separate indicators within a measurement model that becomes unrealistically large.

With a latent interaction procedure (58) first-order and interaction terms are each represented by latent factors. The first-order predictors in the present study (X and Z) were formed as follows: (a) multiple indicators from indirect tests of word association coded as drug-related associations loaded on a factor (loadings ranged from 0.767 to 0.897) of spontaneous drug associations (X), and multiple indicators from the OSPAN loaded on a factor (loadings ranged from 0.635 to 0.728) of WMC (Z). Multiplication terms: X1Z1, X2Z2, and X3Z3, served as the product indicators of the interaction latent factor: (XZ) (58). Factor loadings for the interaction factors ranged from 0.442 to 0.637. The outcome variable (Y) was past year alcohol, tobacco, or marijuana use, which was directly modeled as a manifest variable (see Figure 1 for conceptual model).

The percentage of missing data at baseline across behavioral outcomes and covariates ranged from 2.05% to 4.10%. Mostly because of attrition in this at-risk sample, the percentage of missing data on behavioral outcomes ranged from 40.33% to 41.70% from baseline to Wave 2, and ranged from 43.41% to 43.60% from baseline to Wave 3. The analysis sample sizes were 777, 453 and 438 at baseline, Wave 2, and Wave 3, respectively. Compared to participants with no missing cases, those who had missing cases at either Wave 2 or Wave 3 were significantly older at baseline (16.76±1.04 vs. 16.43±1.00, $p<0.0001$) and reported greater alcohol use in the past year (3.65±3.15 vs. 3.20±2.83, $p=0.04$), but were not significantly different on other baseline characteristics. To avoid biases in listwise deletion of missing data, multiple imputation methods were implemented with SAS Proc MI (71) to generate 10 imputed datasets, which were then used for the SEM analysis in Mplus (68). In addition, an alternative missing data handling approach of Full-Information Maximum Likelihood (FIML) implemented in Mplus was also adopted in the analysis with raw data without data imputation. Consistent findings were observed when results derived from MI and ML were compared as a sensitivity analysis effort. Results from an MI approach are presented here.

Results

General characteristics of the sample are presented in Table 1. Mean age was slightly but significantly higher in males than females. Moreover, compared to females, males also had significantly higher WMC scores at baseline, higher levels of alcohol use in the past year at Wave 2, and higher levels of both cigarette and marijuana use in the past year across the three waves. Alternatively, females had stronger spontaneous alcohol-related associative memories at baseline.

Findings for both cross-sectional and prospective analyses of spontaneous associations (WAT) and working memory capacity (WMC) on the use of alcohol, marijuana and cigarettes are presented in Tables 2, 3, and 4 separately. In cross-sectional analyses with baseline data, spontaneous memory associations on responses to cues of alcohol, marijuana and cigarette use were all significantly related to each specific behavioral outcome in both males and females.

Significant first-order effects in both sexes remained in the prospective analyses with data from Wave 1 to Wave 2 only for alcohol use in the past year and for marijuana use in the past year. Prospective analyses from Wave 1 to Wave 3 revealed sex differences in first-order effects of spontaneous memory associations, with significant effects observed on alcohol use in the past year for males only. Further, prospective analyses from Wave 1 to Wave 3 revealed a significant 1st order effect of spontaneous memory associations for marijuana use in the past year among males.

Cross-sectional analyses with baseline data revealed the only significant first-order effect of WMC was for cigarette use in the past year among females only. Prospective analyses revealed a significant effect of WMC for marijuana use at two-year follow-up among females.

Significant interactions between spontaneous memory associations and WMC were found in the cross-sectional analyses with baseline data on both alcohol use in the past year ($\beta=0.22\pm0.07$, $p=0.001$) and marijuana use in the past year ($\beta=0.13\pm0.06$, $p=0.02$) among females, and cigarette use in the past year among males only ($\beta=-0.22\pm0.08$, $p=0.004$). See Tables 2 through 4 for model fit indices.

Finally, we estimated effect sizes by calculating the difference of variance explained in nested models with and without the theoretical variables. Specifically, residual variances in the dependent variable (e.g. cigarette use in the past year) were retrieved from the final model and a nested model that constrained the paths from the theoretical variables - 1st order (WMC and WAT) and interaction factors (e.g. interaction term of WMC by WAT) - at zero. The difference of the 1-residual variance of the dependent variable between the nested models was calculated and used to reflect the effect size. In the cross-sectional analyses, effect sizes in terms of variance explained by the theoretical factors ranged from 19.4% to 35.9% in alcohol, marijuana and cigarette use for females and males. With respect to the prospective models, it is often difficult to find significant predictors of dependent variables once an adjustment for previous behavior is made in the analysis. After adjusting for baseline drug use, effects sizes in the prospective models were small (~1 to 2.3% of the

variance explained). However, before the adjustment was made, 1st order and interaction effects in terms of variance explained were 15.1% to 33.4% for alcohol use (i.e. model from Wave 1 to Wave 2, and model from Wave 1 to Wave 3), 20.8% to 44.9% for marijuana use, and 34.9% to 42.1% for cigarette use.

Discussion

The present study tested a dual process approach to the understanding of adolescent drug use in an at-risk population over a 3-year period. First, we tested whether drug-related memory associations would more strongly predict drug use over time among adolescents with lower levels of working memory capacity (WMC). Given significant differences in key model measures across sexes, male and female models were analyzed separately. Overall, the results showed little longitudinal support for the dual process synergistic model. However, a few sex differences in models were observed and are described below. Secondly, we tested whether stronger drug-relevant implicit associations would independently predict greater drug use over time and whether poorer WMC would independently predict greater drug use over time. The longitudinal results showed much more consistent support for the importance of the direct 1st order effects of implicit associative memories on drug use over time but limited support for the role of working memory, also described below.

Dual Process Interaction Findings

Cross-sectional results were somewhat consistent with previous findings, which have shown dual process interactions mostly in cross-sectional designs. The analyses reported here revealed cross-sectional interactions between spontaneous associations and WMC among females for past year alcohol and marijuana use and a cross-sectional interaction among males for past year cigarette use. Only the male model findings were consistent with the direction of interaction in our prior cross-sectional research (25,29), which found that drug-relevant associations were *weaker* predictors of cigarette use among adolescents with *higher* WM than among those with lower WM.

The female cross-sectional models revealed a different and unexpected pattern of sex differences. In the female models, drug-relevant associations were stronger predictors of past year alcohol and marijuana use among those with higher WM than among those with lower WM. It is possible that the level of working memory may have been too low to provide sufficient deliberative processing capable of buffering effects of spontaneous drug associations. However, it is also possible that motivational processes that differ from the males in our study affect female alcohol and marijuana use. Van Deursen et al., (72) found WM to moderate the effect of implicit associations on alcohol use in adults among individuals with strong motivation to change. In contrast, WM might facilitate substance use among individuals who have little motivation to restrain from using (or have an intention to drink or use drugs) and have positive feelings toward alcohol or other drugs. Previous research has shown that appetitive behavior among those with better executive function can be directed by explicit attitudes, intentional goals, and motivation (73–75). Hence, it is possible that WM can work in concert with spontaneous associations and interact with explicit or intentional goals and motivation. Tests of three-way effects modifiers of behavior

in at-risk youth are an avenue for further investigation of the source of sex differences involving these variables.

No prospective interactions between spontaneous associations and WMC were found for the three drugs studied.

First-Order Predictive Effects of Spontaneous Memory Associations and Working Memory

Significant predictive effects of spontaneous associative memory processes were found for males and females in all cross-sectional models. In addition, prospectively, at one and two-year follow up, associative memory processes were significant predictors of greater past year alcohol and marijuana use in males. That is, the strength of associations in memory for these behaviors predicted reported behavior at one and two years follow up, controlling for baseline use. In females, spontaneous processes predicted greater past year alcohol and marijuana use at one-year follow-up. These findings are generally consistent with previous studies showing predictive effects of spontaneous processes across a range of populations and for several drugs of abuse, with several reviews (31,76–80). Several other prospective studies have supported important predictive effects of spontaneous associative processes on tobacco, (81–83) alcohol and marijuana use (38,84,85). However, to our knowledge, the present results are the first to highlight 3-year prospective findings for predictive effects of behavior-specific memory associations in at-risk adolescents. Spontaneous associations on word production tasks reflect the likelihood that a given behavior (e.g., alcohol use) will be a spontaneously activated behavioral option when cues, contexts or outcomes related to the behavior are experienced or considered (38). Strong drug-related memory associations are expected to be more spontaneously triggered by relevant cues across a variety of situations and are expected to bias behavior.

With respect to WM predictive effects, only one cross-sectional effect and one longitudinal effect were revealed. It is feasible that the few findings for WM were a result of the neural function not being fully developed as yet in our population at the time of assessment. Working memory is strongly linked to the functioning of the dorsolateral prefrontal cortex (19). This brain region is one of the later regions to fully develop. Gotay et al., (86) found the regions implicated in reasoning and other executive functioning, mediated by the prefrontal cortex, matured during late adolescence and into early adulthood (also see (87). The maturation of this region includes continued cortical sculpting and concomitant function affecting behavioral regulation (88,89) (79,80). Alternatively, some key subcortical structures, like the basal ganglia, implicated in habit formation and reward processing (12) mature earlier in life. Early maturation of habit regions implies that some neural structures are prepared to support the acquisition of appetitive habits, like drug use, by mid-adolescence. As frontal functions are not yet fully developed, the dual process model argues that there will be less of a counterbalance in decision and self-control abilities. At the time of assessment of WM, the youth in this study were mean age 16.62; hence, with respect to appetitive behaviors, these youth may be less reliant on regulatory systems and more vulnerable to drug-mediated spontaneous processes. Further longitudinal evaluation of control processes at various points over adolescence and their effect on behavior is needed to fully understand their role with respect to regulation over drug use.

In sum, interaction effects were found in the cross-sectional models only. WMC was found to be protective only among males. However, longitudinal effects of spontaneous associative memory processes were revealed for the first time in an at-risk adolescent population. The observed sex differences in this study suggest a need for further investigation into mechanisms of control over behavior and motivational factors affecting drug use. A focus on specific regulatory functions, like working memory, can provide more guidance than findings about general broad executive abilities, and a focus on associative memory can help lead to an understanding of how learned associations guide future behavior and habit development.

Limitations

A limitation of the current study was the use of only one test of WM with a limited range in our population. Perhaps use of other executive tests that tap into cognitive resources and control functions would help increase understanding of regulatory processes in at-risk adolescence. In addition, the youth in this study are considered at-risk for drug use, and therefore, generalization of findings are limited to other at-risk adolescents. Further, another limitation was the overall attrition. Given the population in this study is high-risk for various reasons, some participants are simply lost to follow-up despite extensive tracking efforts. However, missing data procedures applied to the data analysis helped reduce possible bias in estimates. Nevertheless, the high attrition could affect generalizability of the findings and could have possibly attenuated the effects. Finally, several observed effects are relatively small even though these effects are statistically significant in our analyses.

Conclusions

This work highlights the role of associative and control process effects on drug use in adolescents at increased risk for drug use over time. Overall, it is clear from this dual process evaluation that drug-relevant memory associations play a key role in drug use behavior in at-risk youth. As such, this work can inform those developing strategic components for prevention programs that tap into associative process systems needed to minimize potential harm in youth at risk for developing drug use habits.

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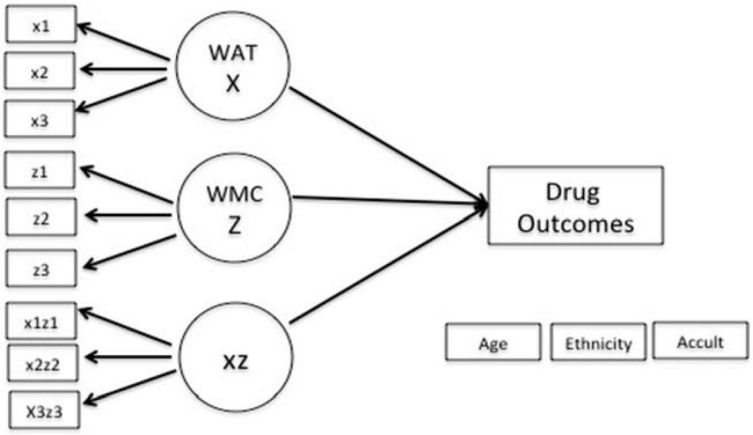

Figure 1.

Figure depicts the conceptual model of the latent variable models tested. WAT= spontaneous drug-relevant memory associations assessed with indirect tests of word association; WMC= Working Memory Capacity assessed with the Operation Span Task; xz= WAT by WMC interaction term. Prospective models tested (Wave 2 and Wave 3) controlled for baseline drug use outcomes (past year cigarette, alcohol and marijuana use).

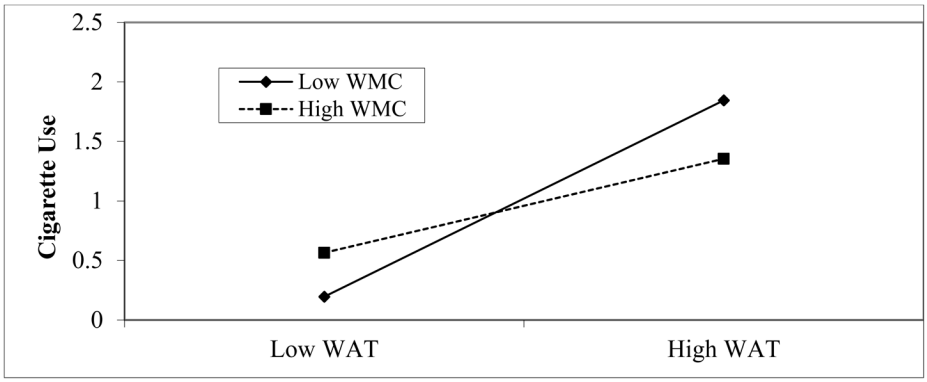

Figure 2.

Figure depicts the nature of the interaction of spontaneous memory associations (WAT) and working memory capacity (WMC) on cigarette use in adolescent males. Notes on simple curves: Low WMC = working memory capacity at the mean minus one standard deviation, and High WMC = working memory capacity at the mean plus one SD. Past year cigarette use was assessed on a rating scale with frequency options ranging from 1 (none) to 11 (91 or more times). Scale represents standardized coefficients.

Table 1

Population Descriptive at Baseline Assessment

Item	All	Male	Female	P
Sex % (N)	100(777)	56.11(436)	43.89(341)	
Age M(SD)	16.62(1.04)	16.72(1.06)	16.49(0.99)	0.002
Ethnicity %(N)				0.29
Native American/Alaska Native	0.40(3)	0.71(3)	0(0)	
Asian	0.53(4)	0.71(3)	0.3(1)	
Black	3.44(26)	2.83(12)	4.22(14)	
Native Hawaiian/Pacific Islander	0.53(4)	0.94(4)	0(0)	
White	13.62(103)	12.74(54)	14.76(49)	
Mixed	16.27(123)	16.98(72)	15.36(51)	
Hispanic	65.21(493)	65.09(276)	65.36(217)	
Acculturation M(SD)	7.37(3.08)	7.34(3.08)	7.40(3.08)	0.80
Working Memory Capacity M(SD)	21.85(10.49)	22.94(10.31)	20.46(10.51)	0.001
Memory Associations of				
Alcohol M(SD)	2.46(3.15)	2.17(2.96)	2.85(3.36)	0.004
Cigarette M(SD)	1.08(2.35)	1.05(2.30)	1.12(2.42)	0.66
Marijuana M(SD)	3.91(4.06)	3.79(4.07)	4.08(4.06)	0.32
Frequency of Alcohol Use in Past Year M(SD)				
Wave 1	3.47(3.03)	3.57(3.15)	3.35(2.86)	0.33
Wave 2	3.30(2.92)	3.66(3.20)	2.91(2.52)	0.005
Wave 3	3.24(2.95)	3.57(3.20)	2.91(2.67)	0.02
Frequency of Cigarette Use in Past Year M(SD)				
Wave 1	3.16(3.42)	3.45(3.58)	2.80(3.16)	0.009
Wave 2	3.00(3.29)	3.53(3.62)	2.41(2.77)	0.0002
Wave 3	3.06(3.51)	3.66(3.85)	2.48(3.04)	0.0004
Frequency of Marijuana Use in Past Year M(SD)				
Wave 1	4.08(3.90)	4.49(4.15)	3.57(3.50)	0.001
Wave 2	3.78(3.90)	4.41(4.26)	3.10(3.34)	0.0003
Wave 3	3.60(3.87)	4.41(4.30)	2.80(3.19)	<0.0001

Note: p values for sex differences were obtained from either the Chi-squared test/Fisher exact test or independent t tests. Means of sum scores for items of acculturation range from 0 to 20, with lower scores indicative of greater acculturation to life in the US. Means of sum scores for items of Working Memory Capacity, with higher scores indicative of better working memory, range from 0 to 42, and Memory Associations of alcohol, cigarette and marijuana use range from 0 to 18. Means of frequencies of alcohol, cigarette and marijuana use range from 1=none to 11= 91 or more times for each drug.

Table 2

Results of Dual Process Analyses for Alcohol Use Regressed on Alcohol-related Memory Associations and Working Memory Capacity with Multiple Imputations

	Male		Female		Model Fit			
	Estimate (SE)	**p**	**Estimate (SE)**	**p**	**χ^2 (df)**	**p for χ^2**	**RMSEA (95% CI)**	**CFI**
Cross-Sectional Analysis of Wave 1 Data								
Past Year Alcohol Use					192.21(108)	<.0001	.045(.035–.055)	0.955
WAT of ALC	0.45(0.05)	<0.001	0.60(0.05)	<0.001				
WMC	0.04(0.07)	0.28	0.04(0.06)	0.54				
WAT X WMC	−0.02(0.08)	0.41	0.22(0.07)	0.001				
Prospective Analysis of Data from Wave 1 to Wave 2								
Past Year Alcohol Use					198.0(120)	<.0001	.041(.030–.051)	0.960
WAT of ALC	0.14(0.07)	0.02	0.15(0.08)	0.03				
WMC	−0.05(0.07)	0.23	−0.04(0.07)	0.28				
WAT X WMC	−0.04(0.09)	0.31	−0.002(0.08)	0.49				
Prospective Analysis of Data from Wave 1 to Wave 3								
Past Year Alcohol Use					189.6(120)	.0001	.039(.028–.049)	0.962
WAT of ALC	0.16(0.08)	0.02	0.03(0.10)	0.38				
OSPAN	0.03(0.09)	0.38	−0.02(0.07)	0.40				
WAT X WMC	−0.03(0.09)	0.36	−0.02(0.11)	0.43				

Covariates in the models: age, acculturation and ethnicity (Hispanic yes/no) and additional control of wave 1 outcome in prospective analysis.

Standardized parameter estimates and standard errors from multiple-group approach structural equation models are presented in this table.

WAT: Word Association Test; WMC: Working Memory Capacity; ALC: Alcohol Use. p values are 1-tailed.

Table 3

Results of Dual Process Analyses for Marijuana Use Regressed on Marijuana-related Memory Associations and Working Memory Capacity with Multiple Imputations

	Male		Female		Model Fit			
	Estimate (SE)	p	Estimate (SE)	p	χ^2 (df)	p for χ^2	RMSEA (95% CI)	CFI
Cross-Sectional Analysis of Wave 1 Data								
Past Year Marijuana Use					114.6(108)	0.31	.013(0–.03)	0.997
WAT of MAR	0.6(0.04)	<0.001	0.61(0.04)	<0.001				
WMC	0.02(0.05)	0.37	0.07(0.05)	0.09				
WAT X WMC	−0.03(0.05)	0.32	0.13(0.06)	0.02				
Prospective Analysis of Data from Wave 1 to Wave 2								
Past Year Marijuana Use					116.0(120)	0.59	0 (0–.23)	1.00
WAT of MAR	0.15(0.07)	0.02	0.17(0.09)	0.02				
WMC	−0.02(0.05)	0.38	−0.001(0.06)	0.49				
WAT X OSPAN	−0.08(0.06)	0.1	0.02(0.08)	0.39				
Prospective Analysis of Data from Wave 1 to Wave 3								
Past Year Marijuana Use					123.2(120)	0.40	.008(0–.027)	0.999
WAT of MAR	0.13(0.07)	0.03	0.06(0.08)	0.25				
WMC	−0.001(0.06)	0.49	−0.12(0.06)	0.03				
WAT X WMC	−0.10(0.07)	0.06	−0.03(0.09)	0.36				

Covariates in the models: age, acculturation and ethnicity (Hispanic yes/no) and additional control of wave 1 outcome in prospective analysis.

Standardized parameter estimates and standard errors from multiple-group approach structural equation models are presented in this table.

WAT: Word Association Test; WMC: Working Memory Capacity; MAR: Marijuana Use. p values are 1-tailed.

Table 4

Results of Dual Process Analyses for Cigarette Use Regressed on Tobacco-related Memory Associations and Working Memory Capacity with Multiple Imputations

	Male		Female		Model Fit			
	Estimate(SE)	**p**	**Estimate(SE)**	**p**	**χ2 (df)**	**p for χ2**	**RMSEA(95% CI)**	**CFI**
Cross-Sectional Analysis of Wave 1 Data								
Past Year Cigarette Use					192.1(108)	<0.0001	.045(.035–.055)	0.961
WAT of CIG	0.61(0.05)	<0.001	0.52(0.04)	<0.001				
WMC	−0.03(0.06)	0.32	0.12(0.06)	0.02				
WAT X WMC	−0.22(0.08)	0.004	0.05(0.06)	0.18				
Prospective Analysis of Data from Wave 1 to Wave 2								
Past Year Cigarette Use					292.6(132)[1]	<0.0001	.06(.047–.065)	0.920
WAT of CIG	0.04(0.06)	0.53	−0.04(0.06)	0.27				
WMC	−0.005(0.07)	0.94	−0.02(0.05)	0.32				
WAS X WMC	0.007(0.08)	0.93	−0.07(0.07)	0.18				
Prospective Analysis of Data from Wave 1 to Wave 3								
Past Year Cigarette Use					183.8(120)	0.0002	.037(.026–.047)	0.968
WAT of CIG	0.06(0.06)	0.17	−0.06(0.06)	0.16				
WMC	−0.03(0.06)	0.33	−0.04(0.07)	0.26				
WAT X WMC	−0.09(0.08)	0.13	−0.04(0.08)	0.33				

Covariates in the models: age, acculturation and ethnicity (Hispanic yes/no) and additional control of wave 1 outcome in prospective analysis.

Standardized parameter estimates and standard errors from multiple-group approach structural equation models are presented in this table.

WAT: Word Association Test; WMC: Working Memory Capacity; CIG: Cigarette Use. p values are 1-tailed.

[1] Covariance between baseline cigarette use and other predictors were not included.