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Trajectories of Cannabis-related Associative Memory among Vulnerable Adolescents: Psychometric and Longitudinal Evaluations

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Abstract

Indirect tests of memory associations relevant to cannabis have been shown to be useful in explaining and predicting adolescent cannabis use habits. This study sought to increase the understanding of adolescent cannabis-related associative memory and cannabis use behavior over time. A longitudinal sample of alternative high school students (N = 775) was assessed yearly for three years. The study first conducted extensive longitudinal measurement analyses of the cannabis-related word association test (WAT) applying contemporary psychometric models. Second, the study examined the longitudinal trajectories of cannabis-related associative memory and cannabis use and their contemporaneous and longitudinal relationships. Results showed that the cannabis-related WAT provided strong evidence of sound psychometric properties. Longitudinal change in cannabis-related associative memory was best described by modeling either a linearly decreasing trajectory or two separate trajectories: During middle adolescence, levels of cannabis-related associative memory were highest and stable but then gradually decreased toward late adolescence. Moreover, cannabis-related associative memory was contemporaneously predictive of cannabis use within ages 15 to 19 while controlling for the underlying growth process of cannabis use and time-invariant covariates (TICs) of gender and lifetime concurrent use of alcohol and cigarettes. Partial support of longitudinal prediction of cannabis use was also obtained from age 17 to 18 and age 19 to 20 while adjusting for growth in cannabis use and the TICs. These results demonstrated that predictive effects of cannabis-related memory associations on cannabis use were detected within some of the one-year age spans and were consistent within ages across adolescent years.

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Keywords

memory associations; implicit cognition; cannabis; adolescents; item response theory; longitudinal

Cannabis is the most commonly used illicit drug among adolescents in the United States (U.S.). A recent national survey reports that the prevalence rate of lifetime cannabis use is 39% among adolescents in grades 9 to 12, of which 22% are the current users of cannabis (Kann, et al., 2016). Cannabis use at this developmental stage is a continuous concern because of its adverse associations with a wide range of health and behavioral outcomes including neurocognitive function deficits (Solowij, et al., 2011), impaired lung function (Howden & Naughton, 2011), poor school performance (Foley, 2006; Homel, Thompson, & Leadbeater, 2014), high risk driving (Blows, Iyers, Connor, Ameratunga, Woodward, & Norton, 2005; O'Malley & Johnson, 2013), and risky sexual behaviors (Bryan, Schmiege, & Magna, 2012). Further, the literature on longitudinal cannabis use patterns suggests that development of cannabis use habit during early to mid-adolescence increases the risk of problem behaviors in later early adulthood such as substance use problems (Flory, Lynam, Milich, Leukefeld, & Clayton, 2004; Lynne-Landsman, Bradshaw, & Ialongo, 2010), and risky sex behavior (Lynne-Landsman, et al., 2010). Early cannabis users and stable light users also have tended to reveal lower educational attainment as compared with abstainers (Ellickson, Martino, & Collins, 2004; Lynne-Landsman, at al., 2010). Taken together, this set of findings strongly suggests that a greater understanding of the developmental trajectory of adolescent cannabis use is needed, especially in populations with particularly high cannabis use rates. However, little is known about longitudinal cannabis use among some of the major sub-populations of adolescents with unusually high rates of cannabis use and hence more likely problems from the substance. One such population is the widespread population of adolescents attending alternative high schools. Cannabis use is quite prevalent in this population, with current use prevalence levels in California as high as 41% — a stark contrast to 14% prevalence among regular high school students (Grana, Black, Sun, Rohrbach, Gunning, & Sussman, 2010). One goal of the present study is to examine longitudinal changes in cannabis use among these students.

A more specific goal of this study is to thoroughly investigate how associative memories related to cannabis use are intertwined with the trajectory of the behavior over time. An associative memory or implicit cognition account of substance use (Stacy & Wiers, 2006, 2010) posits that concepts related to substance use are connected in long-term memory by associative relations, and the processing of a substance-related concept leads to spontaneous activation of closely associated concepts. Consistent with a number of basic theories of memory applicable to risk behavior (Shono, Ames, & Stacy, 2016; Spence & Owens, 1990; Stacy & Wiers, 2006), repeated experience is assumed to strengthen memory associations between substance use and concepts that are encountered and encoded during the drug use episode. Concepts representing situational, social, and affective features of the event are processed and become key features of associations in memory that may prime or channel future behavior and thereby predict later substance use.

One of the frequently used indirect memory tests for assessing spontaneous memory associations relevant to various risk behaviors including substance use is a word association test (WAT; Stacy, 1995; 1997), also referred to as free association (Nelson, McEvoy, & Dennis, 2000), word generation (Thompson-Schill, D'Esposito, & Kan, 1999), or verb generation (Petersen, Fox, Posner, Mintun, & Raichle, 1988) in cognitive psychology and cognitive neuroscience. These types of strategies have been used in part because WATs have been found to be among the best indexes of associations in memory as revealed across diverse cognitive paradigms that rely on these indexes including associative/semantic priming in lexical decision and naming, illusory memory, extralist cued-recall, and other indirect relational tests of memory (Nelson, et al., 2000). In the cannabis-related WAT, participants are presented with a visual cue (e.g., a visual word) and then asked to generate the first behavior or action that comes to mind when reading the cue. Cues may be situational ("with friends"), temporal ("Friday night"), or affective ("feeling happy") in nature, and they may also employ the concept of compound or configural cues by combining different types of features within the cue (e.g., "with friends, feeling good"). Cues in WATs are selected to prompt variability in response patterns that detect individual differences in associations in memory. Thus, cues typically do not mention the target behavior (e.g., cannabis use). Following the associative memory account of risk behavior, the strength of associations in memory is assumed to reflect the extent to which one has experienced co-occurrence of the cue and cannabis use behavior in the same context of everyday life. Hence, more frequent cannabis users are likely to have many more memory associations strongly linked to a concept of cannabis compared to non- or light-cannabis users.

Importantly, indirect instructions are often used in WATs such that participants are not given any explicit reference to what is being tested. A number of studies have revealed that such tests do not require deliberate recollection (e.g., Levy, Stark, & Squire, 2004). Assessments using indirect top of mind instructions in WATs are in contrast to procedures applied in most conventional surveys of predictors of behavior where participants are explicitly asked to answer questions about their thoughts about the behavior of interest (e.g., cannabis). A meta-analytic study of drug-related implicit cognition reported that the substance-related WAT revealed the strongest predictive effects when compared with other indirect tests as predictors of substance use (Rooke, Hine, & Thorsteinsson, 2008).

Tests of spontaneous memory associations relevant to cannabis have been shown to be useful in explaining and predicting adolescent cannabis use habits (Ames, Zogg, & Stacy, 2002; Ames & Stacy 1998; Ames, Xie, Shono, & Stacy, 2017; Krank, Schoenfeld, & Frigon, 2010; Stacy, 1997; for a review, see Krank & Robinson, 2017). Consistent evidence of the predictive utility of these tests among adolescents and other populations also has been reported for tobacco (Grenard, Ames, Wiers, Thush, Sussman, & Stacy, 2008; Kelly, Haynes, & Marlatt, 2008) and alcohol use (Ames & Stacy, 1998; Kelly, Masterman, & Marlatt, 2005; van der Vorst, Krank, Engels, Pieters, Burk, & Mares, 2013).

Notwithstanding successful applications of WATs in both basic and applied research, few studies to date have attempted to examine longitudinal or developmental changes in associative memory for a target behavior and how associations in memory and behavior are intertwined over time. There are compelling reasons to study developmental changes in cannabis-related memory associations from both theoretical and psychometric perspectives. On theoretical grounds, understanding developmental changes in memory associations relevant to substance use would provide new insights into theories of associative memory for substance use, which, in turn, may provide a theoretical framework for new health behavior interventions. From the psychometric perspective, Cronbach and Meehl (1955) argued that (construct) validity should speak to the change or stability of a construct over time. In a longitudinal study, it is essential to consider whether change in the repeated measures of a construct represents a real change or some measurement artifact. One specific measurement artifact that can bias outcomes is differential item functioning (DIF), which occurs when an item's relation to the construct in question changes as a function of group membership or over time. DIF can be handled relatively easily and flexibly by modern psychometric techniques such as item response theory (IRT) modeling. IRT-based DIF analyses, also called "measurement invariance" in the structural equation modeling (SEM) framework, are recommended prior to longitudinal investigations of a construct (Edwards & Wirth, 2009; Reise & Haviland, 2005).

To investigate these issues, this study assessed a sample of alternative high school students over time across ages when cannabis use may change dramatically. The study first conducted extensive longitudinal measurement analyses of the cannabis-related WAT applying contemporary psychometric techniques. Second, building upon the results of the psychometric analyses, this study examined the longitudinal trajectories of cannabis-related associative memory and cannabis use across middle and late adolescent years, and criterion-related validity through both contemporaneous and longitudinal relationships between cannabis-related associative memory and cannabis use. The study sought to increase the understanding of cannabis use and associative memory over time and illustrate the benefits of contemporary longitudinal psychometrics and analysis of change during sensitive ages of development in health behavior.

Method

Data and Participants

Data for the current study came from Project Teenage Stimulant Use, a longitudinal study assessing adolescents' substance use and neurocognitive functioning. The study was approved by the Institutional Review Board at Claremont Graduate University. Participants were recruited from continuation or alternative high schools in the greater Los Angeles area. A total of 786 students agreed to participate in the study and were assessed approximately once per year during a three-year period (the mean elapsed days between waves was 328 days). The current analytic sample with data available on the WAT (see below for more detail on exclusion criteria for the WAT) comprised a total of 775 participants (44% female), where 761 (44% female) took the WAT at Wave 1, 356 (47% female) at Wave 2[1], and 303 (51% female) at Wave 3. Note that although attempts were made to deliver onsite computerized assessments to all participants, some follow-up assessments had to be conducted over phone due to participant constraints such as unwillingness to return to an

[1]14 Participants were allowed to participate in the study starting from Wave 2.

assessment site. At Waves 2 and 3, there were, respectively, 110 and 147 participants who took a phone version of the assessment which did not include the WAT. As a result, the retention rate from Wave 1 to Wave 2 was 61.2% which was similar to other longitudinal studies of students attending alternative high schools (Arpawong, Sussman, Milam, Unger, Land, Sun, & Rohrbach, 2015; Valente, Ritt-Olson, Stacy, Unger, Okamoto, & Sussman, 2007; Sun, Skara, Sun, Dent, and Sussman, 2006).

The participants' ages at Wave 1 were between 14 to 19 years (M = 16.59, *SD* = 1.04). Across the three waves, ages ranged from14 to 21 years, with approximately 98 % of respondents between 15 and 20 years. More than half of the sample (65%) were Hispanic, 16% were mixed race/ethnicity, 14% were non-Hispanic White, 3% were Black, and 2% were other races including Asian, Native Hawaiian/Pacific Islander, and American Indian/ Alaskan Native. Approximately 61% of the participants reported past year use of cannabis at Wave 1.

Attrition patterns were evaluated by comparing responses to key Wave 1 variables between participants who completed all three waves of the assessments and those who dropped out of the assessment after Wave 1. Overall, potential attrition bias in the representativeness of the current analytic sample appeared minimal. The two groups did not significantly differ in age, parents' education levels, English language use, WAT, and frequencies of past year cannabis, alcohol, or cigarette use ($p > .05$ for all comparisons). However, the attrition status was found to be associated with gender such that males were more likely to drop out compared to females (49.1% vs. 34.9%)

Measures

Word association test (WAT)—WAT is an indirect memory test for studying pre-existing associative memory structure and processes (Nelson, et al., 2000; Shono, Ames, & Stacy, 2016). The present study utilized the cannabis-related WAT designed to indirectly assess the retrieval of preexisting memory associations relevant to cannabis use. Twenty-four phrasal cues were selected as stimuli for the present study. Of the 24 cues, 18 were targets that have been shown to elicit cannabis-related responses in prior research (Stacy et al., 1994), and six were fillers unrelated to cannabis use (e.g., "showing respect")[2]. One third of the target cues were single phrases relevant to affective outcomes of drug use (e.g., "feeling good"), one third were compound cues consisting of a combination of location and affective outcome (e.g., "friend's house, having fun"), and one third were a combination of situation, location, and affective outcome (e.g., "Weekend, my bedroom, feeling more relaxed"). Marginal reliability of .78 was previously reported for a reduced set of 15 WAT item responses (Shono, et al., 2014).

Each trial of the task began with presentation of a cue in the middle of a computer screen, along with a task prompt that instructed participants to read a cue and think of the first behavior or action that came to mind. Immediately after the participants pressed the space bar to indicate that they thought of a response, a rectangular box appeared right below the cue, and the participants typed their response using a keyboard. The next trial began without

[2]In Wave 1, only five fillers were used due to an error in the computer program for stimulus presentation

an inter-trial interval right after participants clicked a "next" button or 21 seconds had elapsed after the cue onset, whichever occurred earlier.

Upon the completion of the WAT, a computerized self-coding procedure was administered to score participants' performance on the WAT. In this validated procedure (Krank et al., 2010), pairs of WAT cues and participant's typed responses were presented one by one, along with a list of various behavior categories (e.g., cannabis, alcohol, exercise, etc.). Participants indicated which category from the list was closely related to each of their responses. In the current study, responses to WAT cues were coded 1 when the cannabis category was selected and 0 otherwise. The self-coding procedure has been validated to show that self-coded scores were in agreement with rater-coded scores (Krank et al., 2010, Shono, at al., 2016), yet can more accurately represent memory associations and predict substance use behavior than rater-coded scores can (Krank et al., 2010) likely because participants know the meaning of their own responses better than raters, especially about the meaning of ambiguous responses.

Cannabis use—Frequency of cannabis use (Stacy, Flay, Sussman, Brown, Santi, & Best, 1990) was assessed with a single item using an 11-point rating scale from 0 (none) to 10 (91+ times). Participants were asked to indicate how many times they had used cannabis in the past year.

Other measures—Other variables used in the current study were participants' demographics including age, gender, and ethnicity (Hispanic or non-Hispanic), frequencies of past month alcohol use, past month cigarette use, and lifetime concurrent alcohol and cigarette use. A scale of these drug frequency items was the same as the cannabis use item described above.

Analytic Procedures

The analytic procedures consisted of three major analyses. First, categorical confirmatory factor analysis (CCFA) and IRT analyses were conducted to evaluate the psychometric characteristics of the cannabis-related WAT and to obtain latent trait estimates of cannabis-related associated memory computed for each participant. The two-parameter logistic model (2PLM; Birnbaum, 1968) was selected as the IRT measurement model. Second, longitudinal trajectories of cannabis-related associative memory were examined across ages 15 to 20 in the framework of latent growth curve (LGC) modeling. Third, multivariate LGC models were estimated to test the predictive capability of cannabis-related associative memory with respect to cannabis use over time.

In these analyses, the data were restructured such that the time metric was changed from wave (Waves 1 to 3) to age (ages 15 to 20). In the IRT analyses a random subsample was created in the manner described by Flora, Curran, Hussong, and Edwards (2008). For the participants whose WAT data were available from multiple waves, their WAT data were randomly selected from one of the multiple waves. If the participants took the WAT only at one wave, their WAT data were automatically included with the random subsample. Thus, the analytic data set could include as large a sample as possible with a wider range of participants' ages compared to a wave-based data set (Flora, et al., 2008).

Missing data in both the IRT and LGC analyses were handled with full information maximum likelihood (FIML) estimation which uses all the available data points in parameter estimation and results in less biased parameter estimation than do traditional methods such as listwise deletion (Schafer & Graham, 2002). In the IRT analysis, marginal maximum likelihood estimation with an EM algorithm (Bock & Aitkin, 1981) was used with the flexMIRT software package (Cai, 2013). In the LGC analyses, FIML estimation with robust standard errors was used with M*plus* 6.11 (Muthen & Muthen, 2011). Model fit was evaluated according to the guidelines of Hu and Bentler (1999), using the chi-square goodness of fit statistic, the Tucker-Lewis index (TLI), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA). Model selection among competing LGC models was based on measures of relative model fit including the Akaike information criterion (AIC), Bayesian information criterion (BIC), and substantive considerations.

Results

IRT Analysis

IRT assumption check—To determine the plausibility of fitting a unidimensional IRT model to the WAT data, two assumptions of IRT, unidimensionality and local independence (LI), were examined. First, the underlying factor structure of the 18-item cannabis-related WAT was examined by estimating a one-factor categorical confirmatory factor analysis (CCFA) model[3], with weighted least-squared with mean and variance adjustment (WLSMV; Flora & Curran, 2004). The fit of the one-factor CCFA model was good, χ^2 ($df = 135$) = 359.84, $p < .001$, TLI = .968, CFI = .972, RMSEA = .046, 90% CI [.041, .052]. Standardized factor loadings of 18 WAT items ranged from .53 to .85 (all significant at $p < .01$).

Subsequently, the 2PLMs were estimated to test the LI assumption by assessing two diagnostic measures: Jackknife Slope Index (JSI; Edwards, Houts, & Cai, 2017; Houts & Edwards, 2013) and local dependence chi-square (LD χ^2; Chen & Thissen, 1997). According to the LI assumption, responses to WAT items should be independent of one another after accounting for the latent cannabis-related associative memory. When this assumption is violated, an item pair is said to be locally dependent (LD), and this may lead to biased estimates of item parameters (Chen & Thissen, 1997). In the current study, if the LI assumption check indicated locally dependent item pairs, a series of the 2PLMs were iteratively estimated such that one or more of the potential LD items were removed at a time, and parameter estimates and item fit statistics were evaluated at each iteration to determine which LD item(s) should be excluded from the subsequent analyses. The first item parameter estimates[4] indicated that the following two item pairs, both of which shared the phrase "feeling high," could be locally dependent: (a) items 3 and 10 (JSI = 1.85, LD χ^2 =

[3]Though we could have started with a categorical exploratory factor analysis before CCFA (Edwards, 2009), only the CCFA was conducted for the dimensionality check as we had a relatively strong a priori hypothesis that a single latent variable (i.e., cannabis-related associative memory) underlies performance on the WAT. The unidimensionality of the cannabis-related WAT was also supported in Shono, Grenard, Ames, & Stacy (2014).
[4]In the present study, LD was considered non-ignorable and subjected to further inspection if item pairs exhibited the summed JSI values greater than a critical value and/or the LD χ^2 values were greater than 5. More details on the JSI critical values can be found in Edwards et al. (2017).

8.1) and (b) items 10 and 15 (JSI = 1.65, LD χ^2 = 7.0). The follow-up evaluations of the iterative fit of the 2PLMs suggested retaining item 3 while setting aside items 10 and 15. The next item parameter estimation with 16 WAT items identified three more potential LD item pairs: items 11 and 18, items 9 and 14, and items 12 and 16[5], where items 11, 12, and 14 were excluded resulting in the revised model with 13 WAT items without LD.

Differential item functioning (DIF) analysis—With the plausibly unidimensional set of 13 WAT items, DIF analyses were conducted. DIF is observed when an item has a different item parameter estimate for individuals who are on the same level of the latent trait but belong to different subgroups (e.g., gender groups). It is important to take into account DIF items since the inclusion of DIF items could affect the interpretation of measurement of a construct (Woods et al., 2013). The present study examined DIF across age groups (14–16 vs. 17–20) and gender (male vs. female) using Wald tests in which differences in item parameters between subgroups were compared (see Woods, et al., 2013 for more details).

Results of DIF tests for age groups revealed no statistically significant DIF indicating that all the WAT items functioned equivalently for middle and late adolescent groups after matching them on the latent trait. DIF tests for gender revealed that one item ("friend's house, feeling hyper") showed uniform-DIF, χ^2 (1) = 6.5, p = .01, suggesting that female adolescents (b = .95) tended to associate this item with cannabis more easily than did male adolescents (b = 1.59) after adjusting for group differences on the latent trait.

Final multiple group IRT model—To take into account the gender-DIF item identified above, all items were re-estimated using the multiple-group 2PLM where the item parameter of the DIF item was freely estimated separately for males and females with equality constraints placed on non-DIF items across group. The resulting item parameter estimates are presented in Table 1. The overall fit of the model was good (RMSEA = .04). All the WAT items were strongly related to the latent cannabis-related associative memory. The easiest item to endorse a cannabis-related response was "feeling high" (b = −.21), indicating that a half of the participants who were about one-fifth standard deviation below the average level of the latent trait generated cannabis-related responses given this item. On the other hand, the items, "feeling a rush" (b = 1.96) and "feeling hyper" (b = 1.96) represented the most difficult items to be associated with cannabis use.

Figure 1 displays the test information function (TIF) for male, illustrating the amount of information provided by the cannabis-related WAT regarding cannabis-related associative memory at every level on a latent trait continuum (Though not presented, the TIF for female was almost identical to the TIF for male). Examination of the TIF indicated that the latent cannabis-related associative memory was measured most precisely at approximately one standard deviation above the mean level of the latent trait. The value of information at θ = 1 was equivalent to reliability estimates of .95. Overall, the cannabis-related WAT was very informative at the range of the latent trait between 0 and 2.0 for both male and female.

[5]Although not all the LD measures showed symptoms of potential LD, we selected these three item pairs since the summed JSI values were greater than the critical value and each item pair shared the same phrase, likely evidence for LD.

Trajectories of Cannabis-related Associative Memory

Next, using the IRT-based latent trait estimates of cannabis-related memory associations, longitudinal trajectories of change in cannabis-related associative memory were examined across ages 15 to 20. Because of the lack of previous research, an *a priori* hypothesis of the shape of the trajectory was not specified; however, differential rates of change in *substance use* have been documented across different adolescent age groups in some previous research (e.g., Scheier & Grenard, 2010; Terry-McElrath & O'Malley, 2011), and as such, we reasoned that the trajectory of cannabis-related associative memory might also vary across different age groups such as mid- and late adolescence. Therefore, a latent-basis growth model (McArdle & Epstein, 1987) was first estimated to explore the shape of the trajectory. In this model, the first and last loadings (i.e., ages 15 and 20) for a latent slope factor were fixed to, respectively, 0 and 1, while the remaining four factor loadings (i.e., ages 16-19) were freely estimated. The model fit the data well, χ^2 ($df = 6$) = 8.83, $p = .184$, TLI = .974, RMSEA = .025, 90%CI [0, .058]. Inspection of the model indicated a potential non-linear trend in which the change trajectory could be divided into two pieces according to the estimated latent slope factor loadings (λ_{age} = [0, -.01, .25, .45, .72, 1.0]): (a) from age 15 to 16 (mid-adolescence), during which the percentage of the mean change in cannabis-related associative memory relative to the total change from age 15 to 20 was almost zero ($\Delta\lambda_{15\text{-}16} = .01$), and (b) from age 16 to 20 (late adolescence), during which the rate of change indicated linear decrease. Thus, subsequent analyses tested the following three alternative LGC models each of which characterized different trajectory patterns: a piecewise LGC model with age 16 as an inflection point, a linear LGC model, and a quadratic LGC model. Each of the three models fit the data well (parameter estimates and fit statistics of all the competing LGC models are provided in Supplemental Table S1). Comparisons of the three competing models showed that the piecewise LGC model had the best fit according to AIC whereas the linear LGC model had the best fit according to BIC. Since the differences in the absolute fit indices between these models were minimum (Burnham & Anderson, 2002), both the models were given consideration[6].

For the linear LGC model, examination of the latent slope means indicated that levels of cannabis-related associative memory, on average, decreased from age 15 to 20 ($\mu_\beta = -.10$, $p < .01$). The latent intercept variance was statistically significant ($\Psi_{aa} = .31$, $p < .001$), indicating the presence of individual differences in levels of memory associations at age 15. No individual differences were found in the rate of change in cannabis-related memory associations as the latent slope variance was not significant ($\Psi_{\beta\beta} = .01$, $p < .32$). The covariance of the latent intercept and slope factors was not significant, indicating that levels of cannabis-related associative memory at age 15 were not associated with the rate of change in memory associations.

As for the piecewise LGC model, inspection of the model revealed that the mean of the first latent slope factor was not statistically significant ($\mu_{\beta 1} = .01$, $p = .85$) while the mean of the second latent slope factor was significant ($\mu_{\beta 2} = -.12$, $p < .001$), suggesting that cannabis-

[6]Although the fit of the quadratic LGC model was as good as the other two LGC models, the model was not considered since the latent quadratic slope mean was not statistically significant ($p = .072$).

related associative memory did not show any changes from ages 15 to 16, but then started to decrease from ages 16 to 20. The variance of the second latent slope factor[7] was not significant ($\Psi_{\beta 2\beta 2}$ = .01, *p* = .48), indicating no individual differences in the rate of change in cannabis-related associative memory from ages 16 to 20. The variance (Ψ_{aa} = .22, p < .001) of the latent intercept factor was significant indicating significant individual differences in the mean levels of cannabis-related associative memory at age 16.

The growth trends observed at two distinctive periods of development remained unchanged when a set of covariates, including gender, ethnicity, English language use, lifetime simultaneous use of alcohol and cigarette, and past year cannabis use at age 15 were taken into account (Figure 2). In this conditional model, which fit the data well, χ^2 (*df* = 28) = 46.12, *p* = .020, TLI = .932, RMSEA = .029, 90% CI [.012, .044], gender, simultaneous use of alcohol and cigarettes, and past year cannabis use at age 15 variables had significant effects on the latent intercept factor (*ps* < .001), but not on the two slope factors. Specifically, cannabis-related memory associations at age 16 were, on average, higher for males than females while holding other covariates constant, those who had used simultaneously alcohol and cigarettes more often in their lifetime than those who had not while controlling for other covariates, and those who had used cannabis more often in the past year at age 15 than those who had not adjusting for other covariates. None of the covariates were associated with the two latent slope factors.

Predictive Utility of Cannabis-related Associative Memory

To evaluate evidence of the predictive utility of cannabis-related memory associations for cannabis use, we first investigated longitudinal change in cannabis use over time. The linear LGC model, with adequate fit to the data, χ^2 (*df* = 25) = 46.17, *p* = .006, TLI = .944, RMSEA = .069, 90% CI [.036, .100], was selected as the optimal model for characterizing the trajectory of change in cannabis use from age 15 to 20 (see Supplemental Table S2 for parameter estimates and fit statistics of alternative LGC models). Inspection of the linear LGC model showed that the latent slope mean was significant (μ_β = -.17, *p* = .044), indicating that cannabis use, on average, decreased from age 15 to 20. The latent intercept variance was statistically significant (Ψ_{aa} = 10.56, *p* < .001), indicating significant individual differences in cannabis use at age 15. The latent slope variance was not statistically significant, suggesting no individual differences in the rate of change in cannabis use over time ($\Psi_{\beta\beta}$ = .57, *p* = .182).

Next, expanding the linear LGC model for cannabis use described above, a conditional time-varying covariate (TVC) LGC model was estimated to test the predictive utility of cannabis-related associative memory. In this model, depicted in Figure 3, repeated measures of past year cannabis use across ages 15 to 20 were simultaneously predicted by the latent growth factors for cannabis use, two time-invariant covariates (TICs) of gender and lifetime concurrent use of alcohol and cigarettes, and a TVC of cannabis-related associative memory. This model allowed for testing whether age-specific levels of cannabis-related associative memory predicted the repeated measures of cannabis use at the corresponding ages (e.g.,

[7]Since the first slope factor consisted of two time points (i.e., ages 15 and 16), the variance was fixed at zero for model identification.

prediction of cannabis use at age 16 by cannabis associative memory at age 16) and subsequent ages (e.g., prediction of cannabis associative memory at age 16 on cannabis use at age 17) while controlling for the longitudinal growth trajectory and initial level of cannabis use as well as TICs (Bollen & Curran, 2006). Overall fit of the model was adequate, χ^2 (df = 97) = 167.97, $p < .01$, TLI = .926, RMSEA = .064, 90% CI [.048, .080]. Examination of the model revealed that except within age 20, all the covariate (regression) paths predicting cannabis use from memory associations were significant within ages 15 to 19 (γ's ranging from 2.26 to 3.08). This indicated that cannabis-related associative memory was contemporaneously predictive of cannabis use within ages 15 to 19 while controlling for the influence of the underlying growth process of cannabis use and time-invariant covariates (TICs) of gender and lifetime concurrent use of alcohol and cigarettes. In addition, the regression paths longitudinally predicting cannabis use from cannabis-related associative memory were statistically significant from age 17 to 18 ($\gamma = 1.39$, $p < .001$) and age 19 to 20 ($\gamma = 2.83$, $p < .05$) while adjusting for growth in cannabis use and the TICs.

Discussion

WAT scores have been shown to be useful for assessing individual differences in the pattern of memory associations relevant to a target health behavior. The current study applied modern psychometric methods to comprehensively evaluate psychometric characteristics of the cannabis-related WAT using longitudinal data from a potentially vulnerable adolescent sample. The study also investigated the developmental changes of cannabis-related associative memory and its contemporaneous and longitudinal relationships with cannabis use during the middle and late adolescence years. Our results demonstrated that the revised 13-item cannabis-related WAT provided a multitude of evidence of sound psychometric properties. Longitudinal change in cannabis-related associative memory linearly decreased over time although evidence of non-linear change was also supported. Specifically, during middle adolescence, levels of cannabis-related associative memory were highest and stable but then gradually decreased toward late adolescence. Furthermore, cannabis-related associative memory was contemporaneously predictive of cannabis use within ages 15 to 19 and longitudinally predictive of cannabis use from age 17 to 18 and age 19 to 20 while controlling for the underlying growth of cannabis use and time-invariant covariates (TICs) of gender and lifetime concurrent use of alcohol and cigarettes. Overall, these results demonstrated that predictive effects of cannabis-related memory associations on cannabis use were detected within some of the one-year age spans and were consistent within ages across adolescent years. The following sections consider main findings from both the psychometric and longitudinal evaluations of the cannabis-related WAT as well as the trajectory of cannabis use.

Psychometric Characteristics of the Cannabis-related WAT

Results across multiple lines of evidence showed that the cannabis-related WAT has good psychometric properties after reducing the original 18 items to 13 items. First, CCFA and IRT analyses revealed that WAT item responses were plausibly unidimensional to be accounted for by a single common latent factor of cannabis-related associative memory. Second, all the WAT items were strongly related to the latent cannabis-related associative memory. Third, except for one WAT item, endorsement of cannabis-related responses required moderate-to-high levels of memory associations (i.e., one to two standard deviations above the mean level of the latent trait). Fourth, DIF analyses indicated that the meaning of the WAT items did not differ between middle (ages 14-16) and late (ages 17-20) adolescence once adjusting for the overall differences in the latent trait. This finding was particularly important for the subsequent longitudinal analyses of the cannabis-related WAT since item/measurement invariance assured that any observed changes can be attributed to real change in cannabis-related associative memory rather than any measurement artifacts. Similarly, except for one item, all WAT items were invariant across gender. Note that the gender-DIF item did not need to be excluded from the analysis since the multiple-group IRT analysis allowed for estimating item parameters separately for males and females. Last, the measurement precision of cannabis-related associative memory was observed in the range between average and high levels of the latent trait (i.e., $0 < \theta < 2.0$). All of the above findings are in agreement with a previous study which evaluated the cannabis-related WAT using a cross-sectional sample of the same vulnerable adolescents (Shono, et al., 2014).

Predictive Utility of the Cannabis-related WAT

The current study provided strong evidence of the concurrent validity and partial evidence of the predictive validity of the cannabis-related WAT. First, predictive effects of the cannabis-related WAT for cannabis use were obtained within the same age period except age 20 after adjusting for the latent growth factors of cannabis use and the TICs. Second, the latent trait levels of cannabis-related associative memory at ages 17 and 19 were prospectively predictive of cannabis use at ages 18 and 20 respectively while adjusting for the influence of the normative developmental process of cannabis use and the TICs. These results provide further support for the prospective association between cannabis-related memory associations and cannabis use (Stacy, 1997). It should be noted however that the predictive effects of cannabis-related memory on cannabis use never extended beyond one year, suggesting that cannabis-related associative memory may exert a short-span effect on cannabis use at least among the vulnerable adolescent sample; it is also possible that cues prompting associations for cannabis change after a long period in adolescence and that early cues lose their salience in the long term. This is important as it is related to the issue of the timing of measurement in a longitudinal study. Future longitudinal studies investigating temporal relationship between cannabis-related memory association and cannabis use should not separate measurement occasions more than one year. Further, study of three or six-month intervals, for example, may detect important effects and processes that are masked by longer intervals, despite the common assumption that long intervals yield more rigorous findings in prospective research.

Trajectories of Cannabis-related Associative Memory and Cannabis Use

This study was the first to examine the longitudinal trajectories of cannabis use and cannabis-related associative memory for middle- and late adolescent years among alternative high school students. The LGC analysis of past year cannabis use indicated that levels of cannabis use varied significantly across individuals at age 15 and were in decline linearly from ages 15 to 20. As for cannabis-related associative memory, model comparison findings yielded results favoring both the linear LGC and the piecewise LGC models; these two models were indistinguishable according to the absolute fit indices. Both the models are in agreement in terms of the estimated decreasing trajectory of cannabis-related associative memory from ages 16 to 20. However, the linear LGC model suggested that latent trait levels of cannabis-related associative memory linearly decreased from ages 15 to 20. On the other hand, the piecewise LGC model indicated that latent trait levels of cannabis-related associative memory were highest and stable across ages 15 to 16 and then gradually declined thereafter. Future research should be designed such that these competing alternative models could be better distinguished, for example, by extending age ranges (e.g., inclusion of early adolescents), increasing the sample size, and shortening measurement intervals (e.g., three or six-month intervals). Such designs might enable a study to capture a more complex non-linear pattern of change in levels of cannabis-related associative memory. With a larger age range with both younger and older participants, cannabis-related associative memory might start with a gradual or sharp increase during early adolescence as they are introduced and exposed to cannabis use, followed by either a gradual decrease or a temporary level off at the high level during the mid-adolescence, after which would (continue to) decrease in a linear fashion toward late adolescence. Finally, cannabis-related memory associations might continue the late adolescent trend or perhaps level off in early adulthood.

Nevertheless, the downward pattern of the trajectory of both cannabis use and cannabis-related memory associations from mid to late-adolescence appears to resemble one of the developmental patterns of cannabis use identified in a study by Ellickson, et al. (2004). In their investigation of longitudinal cannabis use patterns from adolescence to early adulthood, four distinctive patterns of adolescent cannabis use were identified with latent growth mixture modeling. One of the groups identified as “early high users” showed highest levels of cannabis use by age 13 and their use of cannabis declined gradually toward late adolescent years. As noted in the introduction, the alternative high school sample used in this study has been characterized as having much higher levels of cannabis use than students in regular high schools (Grana, et al., 2010; Sussman, et al., 1995). Although there may be an important developmental pattern in common across studies of youth with high cannabis use rates in early or middle adolescence, such a comparison should be made with some caution because of the differences in the distribution of age between the present study and that reported by Ellickson et al (2004).

The trajectory of cannabis-related associative memory showed a decreasing trend similar to the pattern of cannabis use. Yet, cannabis-related memory associations had significant age-specific predictive effects on cannabis use above and beyond the effects of developmental change in cannabis use across ages. Given the simultaneous decrease in latent trait levels of cannabis-related memory associations and cannabis use and the contemporaneous prediction of cannabis use by cannabis-related memory associations adjusting for the latent growth process of cannabis use, it is possible that cannabis-related associative memory within one year periods may have decreased prior to decreases in cannabis use. Shorter term prospective designs within single year periods would be necessary to fully investigate this possibility.

In many global memory models and connectionist frameworks, the decreasing trend in cannabis-related associations in memory revealed on the WAT may be due to changes in association strengths, or connection weights, and overall accessibility of cannabis concepts in response to situational and affective cues. Another possible explanation is that youth in middle and late adolescence may have a different size of associative fans (Anderson, 1974) or set-size (Nelson et al., 2000) of responses in the cannabis-related WAT. For example, affective outcome cues (e.g., "feeling good") and situation cues (e.g., "Friday night") could be strongly interconnected with many more concepts in the associative memory network of older adolescents as compared with that of middle adolescents because older adolescents are likely to be exposed to a greater range of affective and situational experiences. Thus, there is the possibility that older adolescents generated responses not related to cannabis although a given WAT cue had a relatively strong association with cannabis as well. If participants are instructed to respond with the first two or three words/phrases that came to mind, more cannabis-related responses might be observable. This is a topic worthy of future investigation.

Limitations

Several limitations of this study should be considered. First, the cannabis-related WAT included only affective outcome, location, and situation cues. Future studies might evaluate the psychometric characteristics of the WAT using other types of cues, and more work may be necessary in uncovering the cues most linked to cannabis use in memory. Second, only cannabis-related associative memory was examined in the current study. Prior research has shown the usefulness of WATs relevant to other risk behaviors including alcohol and cigarette use, and risky sex. Thus, it would be desirable to longitudinally evaluate the psychometric properties of these WATs in future research. Third, because of sparse data at some ages, the growth curve analysis could not include the entire age range of the adolescent sample. It would be ideal if a greater number of repeated measures of memory association and drug use could be obtained in future studies so that a full age range in adolescence could be studied.

Despite these caveats, the current study improves the understanding of the psychometric profile of the cannabis-related WAT and the development of associative memory for cannabis among vulnerable adolescents. The revised 13-item cannabis-related WAT exhibited strong evidence of good psychometric properties in terms of item parameters, measurement precision, item invariance, and concurrent/predictive validity. Levels of cannabis-related associative memory were highest during the middle adolescent years, and then decreased gradually during the later adolescent years. The results also underscore important patterns of cannabis use among high-risk youth and suggest the need for study of shorter intervals of this dynamic period of development.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

Ames SL, Stacy AW. Implicit cognition in the prediction of substance use among drug offenders. Psychology of Addictive Behaviors. 1998; 12(4):272–281. DOI: 10.1037//0893-164x.12.4.272

Ames SL, Xie B, Shono Y, Stacy AW. Adolescents at risk for drug abuse: A 3-year dual process analysis. Addiction. 2017; 112:852–863. DOI: 10.1111/add.13742 [PubMed: 28010052]

Ames SL, Zogg JB, Stacy AW. Implicit cognition, sensation seeking, marijuana use and driving behavior among drug offenders. Personality and Individual Differences. 2002; 33(7):1055–1072. DOI: 10.1016/s0191-8869(01)00212-4

Anderson JR. Retrieval of propositional information from long-term memory. Cognitive Psychology. 1974; 6(4):451–474. DOI: 10.1016/0010-0285(74)90021-8

Arpawong TE, Sussman S, Milam JE, Unger JB, Land H, Sun P, Rohrbach LA. Post-traumatic growth, stressful life events, and relationships with substance use behaviors among alternative high school students: A prospective study. Psychology & Health. 2015; 30(4):475–494. DOI: 10.1080/08870446.2014.979171 [PubMed: 25346382]

Birnbaum, A. Some latent trait models and their use in inferring an examinee’s ability. In: Lord, FM., Novick, MR., editors. Statistical theories of mental test scores. Reading, MA: Addison-Wesley; 1968. p. 395-479.

Blows S, Ivers RQ, Connor J, Ameratunga S, Woodward M, Norton R. Marijuana use and car crash injury. Addiction. 2005; 100(5):605–611. DOI: 10.1111/j.1360-0443.2005.01100.x [PubMed: 15847617]

Bock RD, Aitkin M. Marginal maximum likelihood estimation of item parameters: Application of an EM algorithm. Psychometrika. 1981; 46(4):443–459. DOI: 10.1007/bf02293801

Bollen, KA., Curran, PJ. Latent curve models: A structural equation approach. Hoboken, NJ: Wiley; 2006.

Burnham, K., Anderson, D. Model selection and multimodel inference: A practical information-theoretic approach. New York, NY: Springer; 2002.

Bryan AD, Schmiege SJ, Magnan RE. Marijuana use and risky sexual behavior among high-risk adolescents: Trajectories, risk factors, and event-level relationships. Developmental Psychology. 2012; 48(5):1429–1442. DOI: 10.1037/a0027547 [PubMed: 22390666]

Cai, L. flexMIRT(TM) version 2: Flexible multilevel multidimensional item analysis and test scoring [Computer software]. Chapel Hill, NC: Vector Psychometric Group; 2013.

Chen WH, Thissen D. Local dependence indexes for item pairs using item response theory. Journal of Educational and Behavioral Statistics. 1997; 22(3):265–289. DOI: 10.2307/1165285

Cronbach LJ, Meehl PE. Construct validity in psychological tests. Psychological Bulletin. 1955; 52(4): 281–302. DOI: 10.1037/h0040957 [PubMed: 13245896]

Edwards MC. An introduction to item response theory using the need for cognition scale. Social and Personality Psychology Compass. 2009; 3(4):507–529. DOI: 10.1111/j.1751-9004.2009.00194.x

Edwards, MC., Edelen, MO. Special topics in item response theory. In: Millsap, R., Maydeu-Olivares, A., editors. The Sage handbook of quantitative methods in psychology. New York, NY: Sage; 2009. p. 178-198.

Edwards MC, Houts CR, Cai L. A diagnostic procedure to detect departures from local independence in item response theory models. Psychological Methods. 2017; doi: 10.1037/met0000121

Ellickson PL, Martino SC, Collins RL. Marijuana use from adolescence to young adulthood: Multiple developmental trajectories and their associated outcomes. Health Psychology. 2004; 23(3):299–307. DOI: 10.1037/0278-6133.23.3.299 [PubMed: 15099171]

Flora DB, Curran PJ. An empirical evaluation of alternative methods of estimation for confirmatory factor analysis with ordinal data. Psychological Methods. 2004; 9(4):466–491. DOI: 10.1037/1082-989x.9.4.466 [PubMed: 15598100]

Flora DB, Curran PJ, Hussong AM, Edwards MC. Incorporating measurement nonequivalence in a cross-study latent growth curve analysis. Structural Equation Modeling. 2008; 15(4):676–704. DOI: 10.1080/10705510802339080 [PubMed: 19890440]

Flory K, Lynam D, Milich R, Leukefeld C, Clayton R. Early adolescent through young adult alcohol and marijuana use trajectories: Early predictors, young adult outcomes, and predictive utility. Development and Psychopathology. 2004; 16(1):193–213. DOI: 10.1017/s0954579404044475 [PubMed: 15115071]

Foley JD. Adolescent use and misuse of marijuana. Adolescent Medicine Clinics. 2006; 17(2):319–334. DOI: 10.1016/j.admecli.2006.03.008 [PubMed: 16814696]

Grana RA, Black D, Sun P, Rohrbach LA, Gunning M, Sussman S. School disrepair and substance use among regular and alternative high school students. Journal of School Health. 2010; 80(8):387–393. DOI: 10.1111/j.1746-1561.2010.00518.x [PubMed: 20618621]

Grenard JL, Ames SL, Wiers RW, Thush C, Sussman S, Stacy AW. Working memory capacity moderates the predictive effects of drug-related associations on substance use. Psychology of Addictive Behaviors. 2008; 22(3):426–432. DOI: 10.1037/0893-164x.22.3.426 [PubMed: 18778136]

Homel J, Thompson K, Leadbeater B. Trajectories of marijuana use in youth ages 15–25: Implications for postsecondary education experiences. Journal of Studies on Alcohol and Drugs. 2014; 75(4): 674–683. DOI: 10.15288/jsad.2014.75.674 [PubMed: 24988266]

Houts CR, Edwards MC. The performance of local dependence measures with psychological data. Applied Psychological Measurement. 2013; 37(7):541–562. DOI: 10.1177/0146621613491456

Howden ML, Naughton MT. Pulmonary effects of marijuana inhalation. Expert Review of Respiratory Medicine. 2011; 5(1):87–92. DOI: 10.1586/ers.10.87 [PubMed: 21348589]

Hu L, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling. 1999; 6(1):1–55. DOI: 10.1080/10705519909540118

Kann L, McManus T, Harris WA, Shanklin SL, Flint KH, Hawkins J, Zaza S. Youth risk behavior surveillance - United States, 2015. Morbidity and Mortality Weekly Report. 2016; 65(SS-6):1–174. DOI: 10.15585/mmwr.ss6506a1 [PubMed: 26766396]

Kelly AB, Masterman PW, Marlatt GA. Alcohol-related associative strength and drinking behaviours: Concurrent and prospective relationships. Drug and Alcohol Review. 2005; 24(6):489–498. DOI: 10.1080/09595230500337675 [PubMed: 16361205]

Krank M, Robinson J. Automatic cognitive processes and youth substance use: Risks and Prevention. Current Addiction Reports. 2017; 4(4):386–396. DOI: 10.1007/s40429-017-0168-5

Krank MD, Schoenfeld T, Frigon AP. Self-coded indirect memory associations and alcohol and marijuana use in college students. Behavior Research Methods. 2010; 42(3):733–738. DOI: 10.3758/BRM.42.3.733 [PubMed: 20805595]

Levy DA, Stark CEL, Squire LR. Intact conceptual priming in the absence of declarative memory. Psychological Science. 2004; 15(10):680–686. DOI: 10.1111/j.0956-7976.2004.00740.x [PubMed: 15447639]

Lynne-Landsman SD, Bradshaw CP, Ialongo NS. Testing a developmental cascade model of adolescent substance use trajectories and young adult adjustment. Development and Psychopathology. 2010; 22(4):933–948. DOI: 10.1017/s0954579410000556 [PubMed: 20883591]

Marcotte TD, Bekman NM, Meyer RA, Brown SA. High-risk driving behaviors among Adolescent binge drinkers. The American Journal of Drug and Alcohol Abuse. 2012; 38(4):322–327. DOI: 10.3109/00952990.2011.643981 [PubMed: 22324748]

Muthen, LK., Muthen, BO. Mplus user's guide. 6th. Los Angeles, CA: Muthen & Muthen; 1998–2011.

Nelson DL, McEvoy CL, Dennis S. What is free association and what does it measure? Memory & Cognition. 2000; 28(6):887–899. DOI: 10.3758/bf03209337 [PubMed: 11105515]

O'Malley PM, Johnston LD. Driving after drug or alcohol use by US high school seniors, 2001–2011. American Journal of Public Health. 2013; 103(11):2027–2034. DOI: 10.2105/ajph.2013.301246 [PubMed: 24028266]

Palamar JJ, Ompad DC, Petkova E. Correlates of intentions to use cannabis among US high school seniors in the case of cannabis legalization. International Journal of Drug Policy. 2014; 25(3):424–435. DOI: 10.1016/j.drugpo.2014.01.017 [PubMed: 24589410]

Reise SP, Haviland MG. Item response theory and the measurement of clinical change. Journal of Personality Assessment. 2005; 84(3):228–238. DOI: 10.1207/s15327752jpa8403_02 [PubMed: 15907159]

Rooke SE, Hine DW, Thorsteinsson EB. Implicit cognition and substance use: A meta-analysis. Addictive Behaviors. 2008; 33(10):1314–1328. DOI: 10.1016/j.addbeh.2008.06.009 [PubMed: 18640788]

Schafer JL, Graham JW. Missing data: Our view of the state of the art. Psychological Methods. 2002; 7(2):147–177. DOI: 10.1037//1082-989x.7.2.147 [PubMed: 12090408]

Scheier LM, Grenard JL. Influence of a nationwide social marketing campaign on adolescent drug use. Journal of Health Communication. 2010; 15(3):240–271. DOI: 10.1080/10810731003686580 [PubMed: 20432107]

Shono Y, Ames SL, Stacy AW. Evaluation of internal validity using modern test theory: Application to word association. Psychological Assessment. 2016; 28(2):194–204. DOI: 10.1037/pas0000175 [PubMed: 26053001]

Shono Y, Grenard JL, Ames SL, Stacy AW. Application of item response theory to tests of substance-related associative memory. Psychology of Addictive Behaviors. 2014; 28(3):852–862. DOI: 10.1037/a0035877 [PubMed: 25134051]

Solowij N, Jones KA, Rozman ME, Davis SM, Ciarrochi J, Heaven PCL, Lubman DI, Yücel M. Verbal learning and memory in adolescent cannabis users, alcohol users and non-users. Psychopharmacology. 2011; 216(1):131–144. DOI: 10.1007/s00213-011-2203-x [PubMed: 21328041]

Spence DP, Owens KC. Lexical co-occurrence and association strength. Journal of Psycholinguistic Research. 1990; 19(5):317–330. DOI: 10.1007/bf01074363

Stacy AW. Memory association and ambiguous cues in models of alcohol and marijuana use. Experimental and Clinical Psychopharmacology. 1995; 3(2):183–194. DOI: 10.1037//1064-1297.3.2.183

Stacy AW. Memory activation and expectancy as prospective predictors of alcohol and marijuana use. Journal of Abnormal Psychology. 1997; 106(1):61–73. DOI: 10.1037//0021-843x.106.1.61 [PubMed: 9103718]

Stacy AW, Flay BR, Sussman S, Brown KS, Santi S, Best JA. Validity of alternative self-report indices of smoking among adolescents. Psychological Assessment: A Journal of Consulting and Clinical Psychology. 1990; 2(4):442–446. DOI: 10.1037//1040-3590.2.4.442

Stacy AW, Leigh BC, Weingardt KR. Memory accessibility and association of alcohol use and its positive outcomes. Experimental and Clinical Psychopharmacology. 1994; 2(3):269–282. DOI: 10.1037//1064-1297.2.3.269

Stacy, AW., Wiers, RW. An implicit cognition, associative memory framework for addiction. In: Munafó, M., Albery, I., editors. Cognition and addiction. New York, NY: Oxford University Press; 2006. p. 31-71.

Stacy AW, Wiers RW. Implicit cognition and addiction: A tool for explaining paradoxical behavior. Annual Review of Clinical Psychology. 2010; 6:551–575. DOI: 10.1146/annurev.clinpsy.121208.131444

Sun W, Skara S, Sun P, Dent CW, Sussman S. Project Towards No Drug Abuse: Long-term substance use outcomes evaluation. Preventive Medicine: An International Journal Devoted to Practice and Theory. 2006; 42(3):188–192. DOI: 10.1016/j.ypmed.2005.11.011

Sussman S, Dent CW, Simon TR, Stacy AW, Galaif ER, Moss MA, Craig S, Johnson CA. Immediate impact of social influence-oriented substance abuse prevention curricula in traditional and continuation high schools. Drugs & Society. 1995; 8(3–4):65–81. DOI: 10.1300/j023v08n03_06

Thompson-Schill SL, D'Esposito M, Kan IP. Effects of repetition and competition on activity in left prefrontal cortex during word generation. Neuron. 1999; 23(3):513–522. DOI: 10.1016/s0896-6273(00)80804-1 [PubMed: 10433263]

Valente TW, Ritt-Olson A, Stacy A, Unger JB, Okamoto J, Sussman S. Peer acceleration: Effects of a social network tailored substance abuse prevention program among high-risk adolescents. Addiction. 2007; 102(11):1804–1815. DOI: 10.1111/j.1360-0443.2007.01992.x [PubMed: 17784893]

Van Der Vorst H, Krank M, Engels RCME, Pieters S, Burk WJ, Mares SHW. The mediating role of alcohol-related memory associations on the relation between perceived parental drinking and the onset of adolescents' alcohol use. Addiction. 2013; 108(3):526–533. DOI: 10.1111/add.12042 [PubMed: 23136877]

Woods CM, Cai L, Wang M. The Langer-improved Wald test for DIF testing with multiple groups: Evaluation and comparison to two-group IRT. Educational and Psychological Measurement. 2013; 73(3):532–547. DOI: 10.1177/0013164412464875

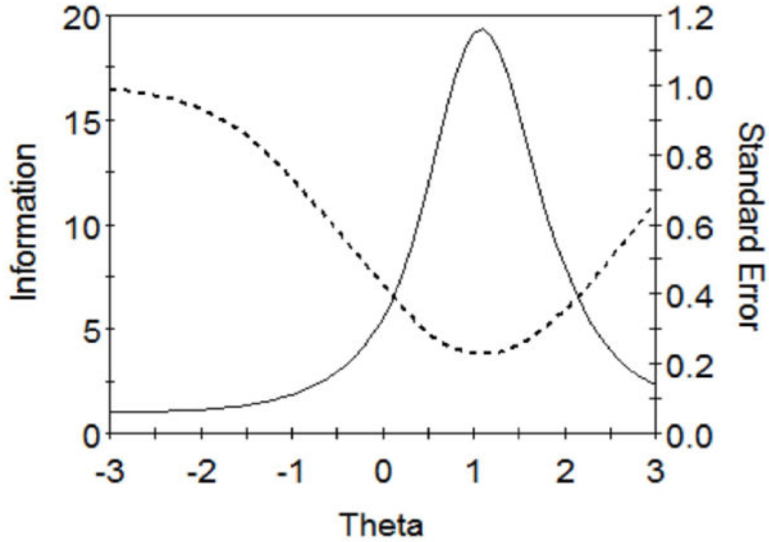

Figure 1.

Test information function (solid line) and standard error function (dashed line). The y-axis on the left indicates the amount of information (*I*), an index of how precisely the cannabis-related word association test estimates the latent trait at a given level of theta. The y-axis on the right shows standard error, which is the inverse of the square root of test information. The x-axis represents the level of theta, or the latent cannabis-related associative memory, with 0 representing the mean level of theta.

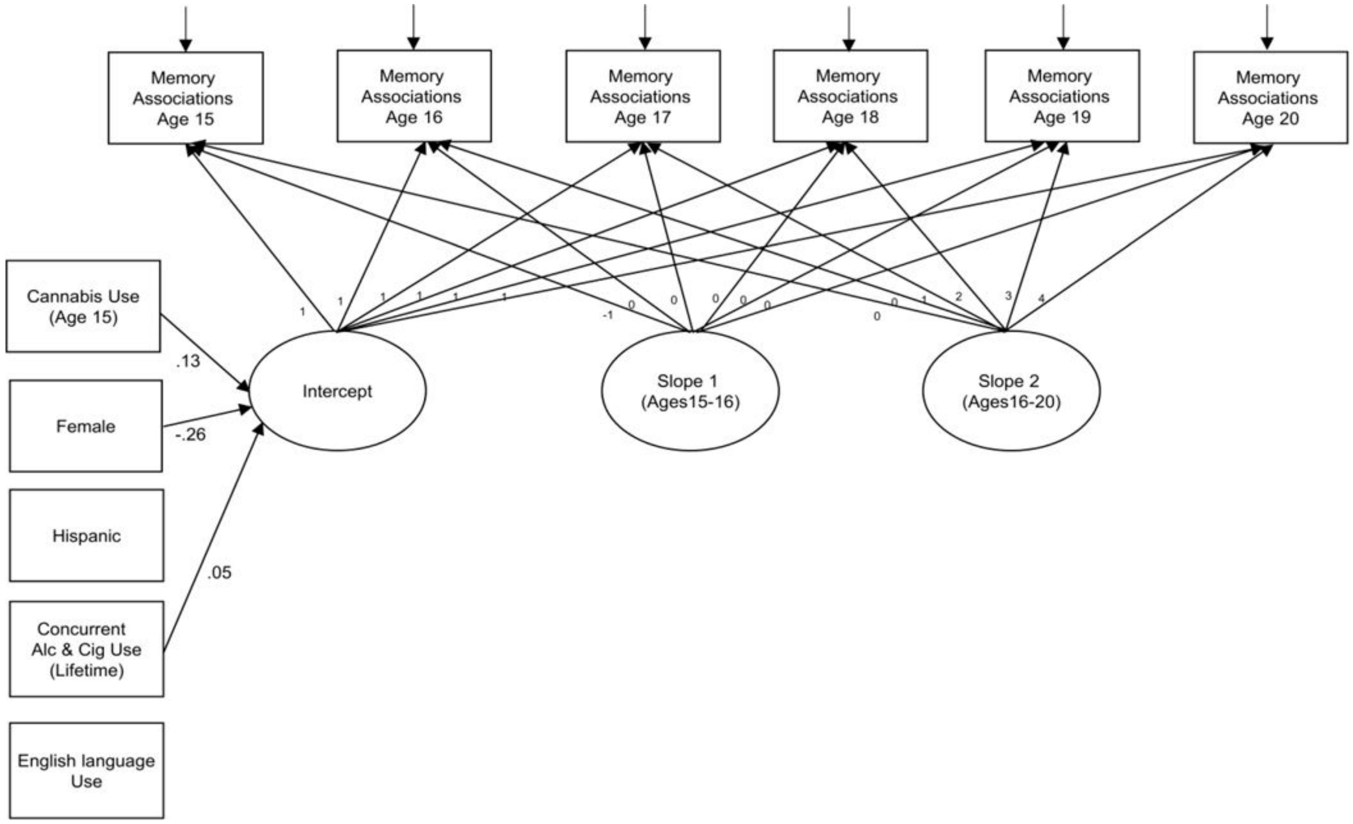

Figure 2.

Conditional piecewise latent growth curve model of cannabis-related associative memory. The latent growth factors (intercept and two slopes) were (a) allowed to covary with one another and (b) regressed on all the covariates (cannabis use at age 15, female, Hispanic, lifetime concurrent use of alcohol and cigarettes, and English language use). Only the significant paths are shown. Alc = alcohol use; Cig = cigarette use.

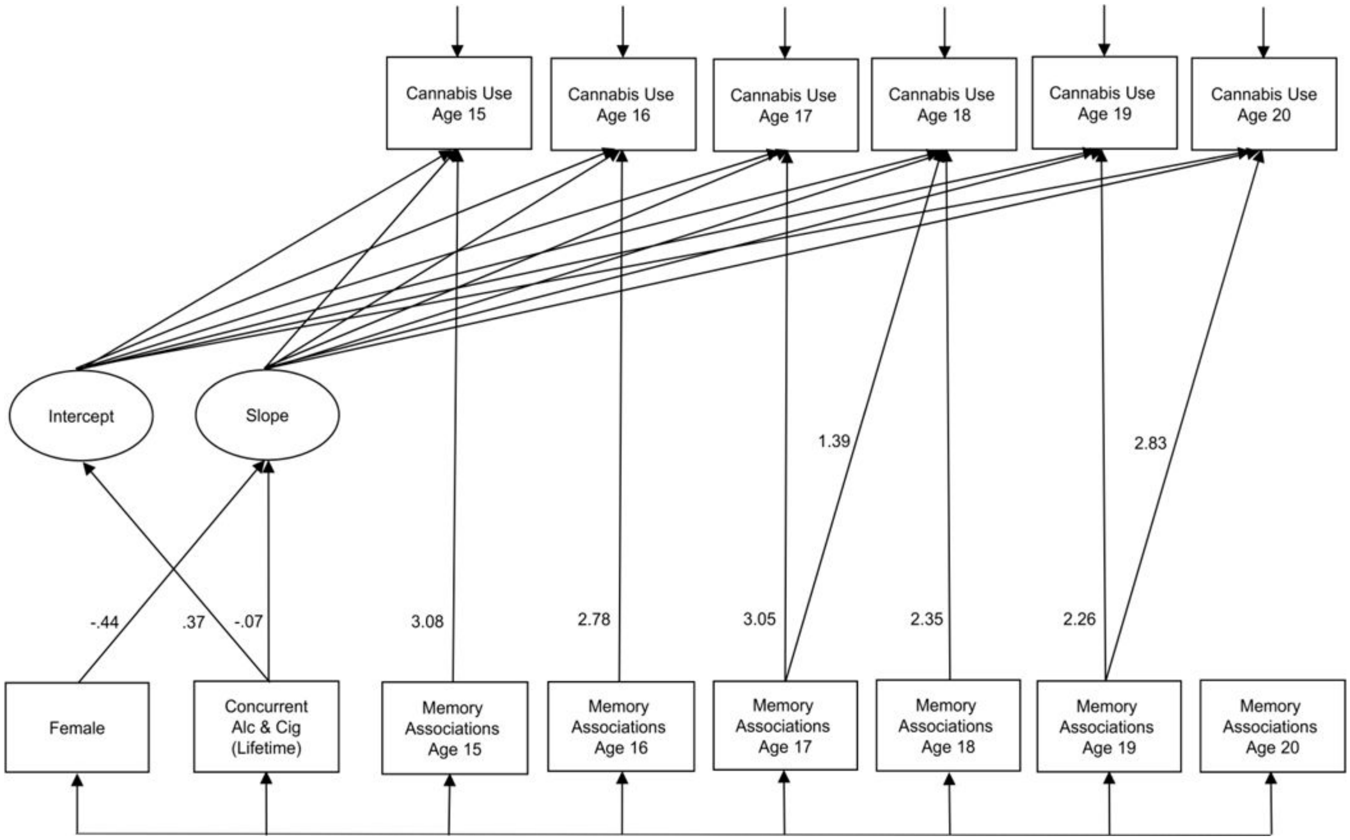

Figure 3.

Conditional time-varying covariate latent growth curve model of cannabis use and cannabis-related associative memory. The loadings on the latent slope factor represent a linear trajectory of cannabis use. The loadings on the intercept factor were fixed to 1 at each age. The single-headed arrows from the time-invariant covariates (female and lifetime concurrent use of alcohol and cigarettes) to the latent growth factors (intercept and slope) and from the time-varying covariates (memory associations at each age) to the repeated measures of cannabis use at each age denote regression paths. Only the significant paths are shown. The double headed arrows connecting pairs of covariates denote correlations. The correlations were examined for significance but results are not shown. Alc = alcohol use; Cig = cigarette use.

Table 1

Item parameter estimates for the final two-parameter logistic model.

	WAT Items	*a*	SE	*b*	SE
1.	Feeling hyper	1.51	0.27	1.95	0.35
2.	Feeling good	2.26	0.30	0.89	0.12
3.	Feeling high	1.85	0.21	−0.21	0.02
4.	Feeling more relaxed	2.73	0.36	0.97	0.13
5.	Forgetting problems	2.17	0.28	0.95	0.12
6.	Feeling a rush	1.65	0.27	1.96	0.32
7.	My bedroom, feeling good	2.94	0.45	1.33	0.20
8.	My bedroom, feeling more relaxed	3.30	0.48	1.13	0.16
9.	Friend's house, feeling hyper	2.39	0.37	1.46/1.05[a]	0.22/0.16[a]
10.	My bedroom, feeling high	–	–	–	–
11.	Friend's house, feeling a rush	–	–	–	–
12.	Friend's house, having fun	–	–	–	–
13.	Friend's house, hanging out, feeling good	3.32	0.43	0.93	0.12
14.	Friday night, my bedroom, feeling hyper	–	–	–	–
15.	Weekend, party, feeling high	–	–	–	–
16.	Friday night, friend's house, having fun	3.00	0.39	0.93	0.12
17.	Weekend, my bedroom, feeling more relaxed	2.58	0.35	1.19	0.16
18.	Weekend, friend's house, feeling a rush	2.14	0.36	1.45	0.24

Notes. a = item discrimination parameter; b = item difficulty parameter.

[a]Item parameter was estimated separately for male and female to take into account DIF.