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Working memory capacity and addiction treatment outcomes in adolescents

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Abstract

Background—Brief addiction treatments including motivational interviewing (MI) have shown promise with adolescents, but the factors that influence treatment efficacy in this population remain unknown. One candidate is working memory, the ability to hold a fact or thought in mind. This is relevant, as in therapy a client must maintain and manipulate ideas while working with a clinician. Working memory depends upon brain structures and functions that change markedly during neurodevelopment and that can be negatively impacted by substance use.

Objectives—In a secondary analysis of data from a clinical trial for adolescent substance use comparing alcohol/marijuana education and MI, we evaluated the relationship between working memory and three-month treatment-outcomes with the hypothesis that the relationship between intervention condition and outcome would be moderated by working memory.

Methods—With a diverse sample of adolescents currently using alcohol and/or marijuana (N=153, 64.7% male, 70.6% Hispanic), we examined the relationship between baseline measures of working memory and alcohol and cannabis-related problem scores measured at the three-month follow-up.

Results—Results showed that lower working memory scores were associated with poorer treatment response only for alcohol use, and only within the education group. No relationship was found between working memory and treatment outcomes in the MI group.

Conclusion—Results suggest that issues with working memory capacity may interfere with adolescents' ability to process and implement didactic alcohol and marijuana content in standard education interventions. These results also suggest that MI can be implemented equally effectively across the range of working memory functioning in youth.

Introduction

Among adolescents, problem use of alcohol continues to be high and rates of cannabis misuse are on the rise (1,2). In the United States, alcohol and marijuana use triples during

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the high school years (3–5). By the time youth reach their senior year most have tried alcohol and cannabis at least once (4) and many youth report regular use of these substances (6). Youth who are involved with the justice system are at even higher risk for alcohol and marijuana use and misuse (7). Substance use disorders are ubiquitous in juvenile justice settings and are related to later adult use, making these settings an important target for interventions with high-risk youth.

In addition to placing youth at greater risk for alcohol and marijuana use and related problems during adulthood (8,9), alcohol and marijuana exposure during adolescence can have profound health consequences. Adolescence is a time of drastic change in brain structure and function, characterized by synaptic “pruning”, which increases efficient function of the developing brain (10). Maturation of brain grey and white matter continues throughout adolescence and into the early twenties, beginning with brain areas necessary for basic life-sustaining function and ending with cortical development that drives higher-order cognitive skills (11). While there are still questions around the nature of impact on the developing brain, alcohol and cannabis use during this developmental period are linked to both structural and functional differences for adolescents (12,13).

This pattern of neurocognitive development is relevant, as development of higher-order cognitive skills, particularly those executed in critical frontal regions of the brain, directly impact an individual's ability to engage the cognitive processes requisite for successful behavioral treatment. That is, for certain types of treatment to “work” individuals must be able to hold certain ideas in mind, while simultaneously considering their history, as well as evaluating new ideas about what behaviors they have engaged in and what they may want to change (14). This is relevant because alcohol and cannabis use have been linked to disruption of these very processes, including impaired working memory capacity (15,16). At the same time, lower working memory performance before the initiation of substance use has been predictive of poorer long-term adolescent substance use outcomes (17,18). Despite this, the role of working memory in adolescent substance use treatment has not been explicitly examined. Ultimately, in understanding who responds to therapy (and who does not), it is critical to evaluate neurocognitive variables like working memory in adolescent clients, as these measures may be key to understanding the relationship between adolescent neurocognition, therapeutic interventions, and intervention outcomes.

One intervention that holds potential for adolescents is motivational interviewing (MI: 19). MI is a directional, non-confrontational, client-centered approach focused on promoting positive behavior change. Among adults, MI is a strong empirically-supported treatment for improving health risk behaviors, with an average short-term between-group effect size of $d=0.77$ (20). MI is increasingly gaining empirically supported treatment for adolescent substance use, with recent studies finding somewhat smaller effects in adolescents ($d=0.16$: 21). This is particularly important for justice-involved youth, who are *more* likely to meet lifetime criteria for alcohol use disorders (22,23), but *less* likely to receive treatment for alcohol use disorders (24,25). Critically, variability in working memory and related brain development (26) offers one potential explanation for why MI may be less effective in youth. During an MI session, an empathic clinician helps a client explore a behavior change through a discussion of factors favorable to and unfavorable to that behavior change (27). In

such an exchange there may be effects of intervention content such as clinician empathy (26,27) that interact with client neurocognitive features like working memory. Recent theoretical models (14) also suggest that in youth, MI is likely to operate in part by requiring clients' generation of their personal story around substance use. This includes a person's self-representation, memory for personally experienced events, and – critically – working memory. That is, individuals must be able to access, retrieve, and process these thoughts while communicating with the clinician.

This literature suggests a pattern in which normal variation in adolescent working memory could tenably disrupt or interfere with successful treatment response. If adolescents show different treatment outcomes by working memory function, it could facilitate more precise selection and implementation of programming tailored to specific adolescent clients. We thus aimed to disentangle these relationships by examining the role of working memory in treatment response for substance-using youth, with a focus on high-risk, justice-involved youth, who have greater need for interventions to reduce alcohol abuse than do other youth. We used MI and an educational control condition (alcohol/marijuana education) to evaluate whether the relationship between treatment condition and three-month outcomes (alcohol- and marijuana-related problems) would be moderated by working memory. We hypothesized that in the MI group, higher working memory capacity would be associated with better three-month treatment outcomes (less alcohol and cannabis use), with no effect of working memory in the alcohol/marijuana education group.

Method

Participants

This study was part of a larger clinical trial evaluating health disparities (28). Results for the parent trial, including study flow and overall 3-month treatment outcomes can be found elsewhere (29). In the present study, all analyses are focused on the sample for which a working memory index was available, from the Wechsler Intelligence Scale for Children (WISC: 30) for youth 16 years of age, or the Wechsler Adult Intelligence Scale (WAIS: 31) for youth >16 years.

All procedures were conducted with local institutional review board approval and a federal Certificate of Confidentiality. Youth were invited to participate in a study aimed at improving adolescent health. Research staff introduced the project at local juvenile justice programs, underscoring that participation was voluntary and separate from justice involvement. Youth completed informed written assent. Audio-recorded informed parent/guardian consent was obtained via telephone after youth assent. To participate, youth had to be between 13-18 years old, involved with a justice program, and a regular substance user, defined as using alcohol and/or cannabis at least once per month for the past six months. Exclusion criteria included active psychosis, mental retardation, neurodevelopmental disorder, and/or severe medical illness, as determined by project staff and/or parent report. Participants were compensated up to \$ 160 for the time and inconvenience of completing study procedures.

Measures

Participants completed questionnaires via individual laptops (ACASI: 32). Measures for this study included demographics, alcohol-related problems, (Rutgers Alcohol Problems Index (RAPI: 33), and marijuana-related problems (MJP: 34). Working memory was assessed using the working memory subscales of the WISC or WAIS, as appropriate. The baseline assessment and first intervention session (MI or alcohol/marijuana education) were held on the same day.

Wechsler intelligence scales—The WAIS-IV (31) and WISC-IV (30) each include three working memory subtests: digit span, arithmetic, and letter-number sequencing. In the digit span subtest, sets of 2-9 numbers are spoken aloud to youth. Participants are to either repeat the numbers in the same order (digit span forward), repeat the numbers in reverse order (digit span backward), or repeat the numbers in numerical order (digit span sequencing). In the arithmetic subtest, word problems of varying complexity are either presented visually (for counting problems) or spoken aloud to youth (for addition, subtraction, multiplication, division, and percentages). Each problem has a 30-second time limit. In the letter-number sequencing subtest, sets that include both letters and numbers are spoken aloud to participants. For each set, the youth must repeat back the letters from the set in alphabetical order first, followed by the numbers from the set in numerical order. Scores on each subtest are converted to scaled scores based on age group, and then summed to produce a sum of scaled scores, the working memory index.

Procedures

Youth completed a baseline assessment and were randomized to time-matched individual sessions of MI or alcohol/marijuana education. All sessions were conducted on-site at the site of the collaborating juvenile justice programming. All youth received two, one-hour sessions, spaced approximately one week apart to provide youth with an opportunity apply new knowledge, insights, and commitments to behavior change in potentially risky environments in the intervening weekend. The mean time between sessions was 8.34 days (SD = 4.28). All youth in this project (100%) attended both treatment sessions. All sessions were audio recorded with youth permission. In line with other IRB-approved protocols for this project, although the local juvenile justice system conducts regular drug testing with youth, the study did not have and did not seek access to drug test results for study participants, in order to protect participant confidentiality and to maintain the intervention as a safe space for youth to speak freely without fear of repercussions. There was no reason to believe that any participants were intoxicated at the time of any study contact; no youth were rescheduled due to concern about intoxication.

Motivational Interviewing (MI)—All MI sessions followed a manualized format that focused on reducing youths' alcohol and cannabis use. MI integrity and fidelity were monitored and maintained by the last author, who reviewed randomly-selected sessions with counselors during supervision. Counselors were trained to be MI-consistent, using reflections and affirmations to show empathy, support self-efficacy, and reduce resistance. The Motivational Interviewing Treatment Integrity Scale (MITI 3.1.1; 35), which includes

both global ratings of MI constructs and counts of specific interventionist behaviors, was used to evaluate intervention integrity.

Alcohol/Marijuana Education—This condition was designed to mirror standard drug and alcohol information provided in juvenile justice settings. This manualized intervention was matched for time and counselor contact to the MI. Integrity and fidelity approaches paralleled the MI condition. Counselors were instructed to be didactic, providing one-on-one tutoring in the content areas of alcohol and cannabis. Counselors invited youth to ask questions about presented information. In alcohol/marijuana education, counselors did not elicit or reflect youth perspectives.

Three month behavioral follow-up—Follow-ups were completed in person at a convenient location for youth (e.g., research center, Starbucks). Youth reported their past-month alcohol- and cannabis-related problems and quantity/frequency of substance use using parallel measures to the baseline. The follow-up rate at three months was 95.3%.

Analysis Plan

Group equivalence and retention were assessed using *t*-tests and Fisher's exact test. Our prior analysis in this sample indicated no significant outcome differences between treatment conditions at 3 months (29). We focused the study analyses on alcohol and cannabis-related problems scores (i.e., RAPI and MJP) measured at the three-month follow-up (3-mo); each analysis covaried for the baseline measure of the dependent variable. For each outcome, we hypothesized that the relationship between by intervention condition (MI vs. alcohol/marijuana education) and outcome would be moderated by working memory. Simple slopes analysis was used to evaluate interaction effects. Only participants with valid data for the three-month follow-up were included in the demographics. Full-information maximum likelihood (FIML) was used for all outcome analysis, conditioned on data from all subjects who completed baseline neuropsychological assessment (36). This procedure allows cases with some missing data to influence the results.

Results

Demographics

This sample contained $N = 154$ adolescents with complete working memory (i.e., WISC or WAIS) data. The sample was primarily male (67.4%) and Hispanic (70.6%). Participants were on average 16.2 years of age ($SD=1.2$) and had 9.8 years of education ($SD=1.5$). All reported high rates of baseline substance-related problems. The MI and alcohol/marijuana education groups differed only on the highest grade completed at the time of study enrollment, with a slightly higher grade completed for alcohol/marijuana education than for MI ($p < .05$); however, age did not significantly differ between groups, and we found no other evidence of differences between participants in the two groups. Complete demographic characteristics and group comparisons are given in Table 1.

Study retention

All adolescents in this sample completed both intervention sessions, with no differences in follow-up completion between groups ($X^2_{(439)} = 2.043, p = .153$).

Outcome analysis

Of the predictors examined, only baseline alcohol-related problems score and the Working Memory $\times$ Treatment Group interaction term were significant predictors of alcohol-related problems at the three-month follow-up (estimate = 0.057, $p < .01$). That is, the effect of working memory on the alcohol-related problems score at three months was conditional on Group. Complete model results can be found in Table 2a. No significant effects were detected for cannabis-related problems other than the baseline measure (see Tables 2b and 3).

Moderated effects

Simple slopes analysis indicated that the lower working memory scores predicted more alcohol-related problems for youth in the alcohol/marijuana education condition (gradient = -0.091, $t = -2.841, p = .005$) but not the MI condition (gradient = 0.023, $t = 0.755, p = .451$). That is, only adolescents in the alcohol/marijuana education group showed an effect of working memory scores on treatment outcomes, with youth with poorer working memory scores showing more alcohol-related problems three months post-treatment.

Discussion

This study is a compelling addition to the broader literature on which treatment approaches works for which youth, and why. Here, we found that the effect of working memory capacity on treatment outcomes was conditional on intervention group. That is, for youth in a standard alcohol and marijuana education approach, lower working memory capacity, as measured by the standard and widely-used Wechsler scales, was related to poorer three-month treatment outcomes for alcohol-related problems. Contrary to our a priori hypotheses, we found no evidence of relationships between working memory and treatment outcomes for youth in the MI condition. These results suggest that for youth in the alcohol and marijuana education condition, working memory capacity modulated youths' ability to benefit from this didactic treatment approach.

The precise mechanism underlying the relationship between working memory and substance use is unclear. Some recent work has suggested that lower working memory capacity, and lower executive function more generally, is a risk factor for substance use. For instance, a prospective study of substance-naïve adolescents indicated that lower working memory capacity was related to an earlier initiation of alcohol use (37). Work with frequent cannabis users has indicated a similar effect, with lower working memory predicting more cannabis-related problems (38). However, in other research using a national sample of extremely behaviorally severe youth, *higher* WASI full-scale scores were related to *heavier* alcohol use over the course of a 7 year longitudinal examination of justice-involved male youth (7). Although it seems intuitive that different aspects of cognition would impact treatment

response, few studies have had the opportunity to empirically examine the role of different cognitive capacities in successful adolescent addiction treatment outcomes (14).

Contrary to our hypothesis, in the present study working memory was *less* important in the MI condition. It may be that the empathic nature of MI facilitates youths' complicated cognitive task of considering, within a session, how their substance use might impact their later life choices and options. In MI, youth are not required to complete a set of prescribed tasks, but are instead engaged and given the space to tell their own story and explore their ambivalence. This space and process may bolster and support these cognitive efforts, even among youth who have lower working memory capacity. In addition, it may be that to some degree the MI counselor supports a youth's working memory, with behaviors like reflections and questions maintaining content that might otherwise have faded from working memory, limiting the influence of lower working memory capacity. Or, it may be that for youth in didactic interventions like alcohol/marijuana education, alcohol-related problems persisted in youth with lower working memory capacity because the educational content knowledge was not successfully absorbed in a way that could be sustained in the long term. In other words, low working memory capacity may limit youths' successful acquisition and improvement of the very skills that would help them begin to make behavior changes in their alcohol use. Further work must begin to disentangle how this particular treatment outcome may be dissimilar from other alcohol-related outcomes and from outcomes for other substances including marijuana.

Our results also indicated an effect for alcohol outcomes, but not for marijuana outcomes. Why might this be? Some recent research has suggested that neurocognitive effect for alcohol and marijuana use seem to differ by substance. One study of executive function in adolescents found that alcohol use, but not marijuana use, was associated with brain activation during task performance (39). Another indicated that adolescents who used only tobacco, but not polysubstance-using youth or those who used only alcohol, showed decreased brain activation in reward systems (40). In the present study, however, we cannot determine whether these effects are caused by past alcohol and marijuana use, or whether instead neurocognitive function led to substance-specific effects for alcohol and marijuana.

Finally, decreased working memory capacity may also be related to a reduced ability to later remember or implement the decisions made within a session; that is, prospective memory may be limited by lower working memory capacity (41,42). Such effects would be expected not only in alcohol/marijuana education, but in many other behavioral interventions for alcohol and marijuana use. Ultimately, these outcomes continue to highlight the absence of information on how adolescent alcohol and marijuana use treatments operate in youth, particularly on a cognitive level (29,43,44).

Conclusions and Limitations

While measures of working memory are widely used in adolescent neuropsychology, some have challenged that these measures inadvertently reflect other influences such as socioeconomic level, degree of education exposure, and experience, rather than any innate cognitive capacity (45,46). The observed differences in treatment response in working

memory for youth in the alcohol/marijuana education and MI groups may therefore reflect attributes of the tests themselves. However, because youth in these intervention groups did not differ significantly on these demographic characteristics, this explanation seems less likely.

It is also important to note the constructs that we were unable to evaluate – for instance, in other work, working memory capacity is related to grey and white matter development (11,47). Neurocognitive measures of executive function such as the Stroop task (39,48) and response inhibition tasks (49,50) have also demonstrated relationships with adolescent cannabis and alcohol use, and other measures may hold similar potential. Future work should examine these neurodevelopmental factors in conjunction with within-session process coding measures (e.g. 51–53) to reveal any effects of neurocognition on session content.

Our finding that working memory capacity influences alcohol outcomes supports the notion that neuropsychological constructs are useful in and can be incorporated into personalized treatment for adolescent substance dependence. The present study also underscores the importance of continuing to empirically examine the process of youth treatment response so that we have a better idea of which mechanisms of behavior change are important in this age group. For now, this emerging body of research offers more questions than answers (54–56).

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Table 1
Demographics and group equivalence

Measure	Group mean (SD)		<i>t</i>
	AME (n=85)	MI (n=69)	
Participant Age	16.27 (1.14)	16.04 (1.09)	1.25
Working memory index [^]	17.52 (4.36)	16.36 (4.35)	1.64
Highest grade completed	10.02 (1.37)	9.5 (1.53)	2.23 *
Age of onset (years)			
Alcohol	12.12 (2.91)	12.57 (2.58)	-1.01
Cannabis	11.66 (2.43)	11.88 (2.12)	-0.60
Baseline substance use			
RAPI total score	10.76 (9.79)	10.48 (10.51)	0.16
MJP total score	23.68 (17.97)	25.05 (19.14)	-0.44
Three-month substance use			
RAPI total score	9.84 (12.01)	10.05 (10.18)	-0.11
MJP total score	16.11 (13.07)	20.24 (20.62)	-1.40

Note. AME = Alcohol/marijuana education; RAPI = Rutgers Alcohol-related Problems Index; MJP = Marijuana Problems Index.

[^] = Sum of scaled scores;

* = $p < .05$

Table 2

Effects of working memory and group on alcohol outcomes

a. Alcohol-related Problems

Variable	Coeff.	SE	t	p	95% CI	
					Lower	Upper
Constant	1.641	0.121	13.591	.000	1.404	1.878
WM	-0.034	0.022	-1.521	.128	-0.077	0.010
Group (MI vs AME)	0.009	0.088	0.102	.919	-0.163	0.181
WM × Group	0.057	0.022	2.597	.009	0.014	0.100
Baseline RAPI	0.049	0.009	5.439	.000	0.031	0.067

b. Binge drinking days

Constant	0.352	0.132	2.663	.000	0.093	0.610
WM	-0.004	0.019	-0.196	.844	-0.041	0.033
Group (MI vs AME)	0.002	0.089	0.023	.982	-0.172	0.176
WM × Group	0.035	0.020	1.816	.069	-0.003	0.074
Baseline binge days	0.097	0.039	2.509	.012	0.021	0.173

Note. WM = working memory. RAPI = Rutgers Alcohol Problem Index. AME = alcohol/marijuana education. Group = MI (coded as 1) and AME (coded as -1).

Table 3
Effects of working memory and group on cannabis outcomes
a. Marijuana-related Problems

Variable	Coeff.	SE	t	p	95% CI	
					Lower	Upper
Constant	2.141	0.162	13.213	.000	1.824	2.459
WM	-0.023	0.027	-0.882	.378	-0.076	0.029
Group (MI vs AME)	0.070	0.088	0.799	.424	-0.102	0.243
WM × Group	-0.005	0.026	-0.201	.840	-0.057	0.046
Baseline MIP	0.027	0.006	4.258	.000	0.014	0.039

b. Cannabis use days

Constant	1.219	0.180	6.777	.000	0.867	1.572
WM	-0.001	0.024	-0.030	.976	-0.048	0.047
Group (MI vs AME)	-0.133	0.126	-1.061	.289	-0.380	0.113
WM × Group	-0.007	0.024	-0.285	.776	-0.054	0.041
Baseline cannabis days	0.063	0.017	3.674	.000	0.029	0.097

Note. WM = working memory. MIP = Marijuana-Related Problems. AME = alcohol/marijuana education. Group = MI (coded as 1) and AME (coded as -1).