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ORIGINAL INVESTIGATION

Prospective memory impairment in former users of methamphetamine

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Abstract
Rationale Considerable research indicates that methamphetamine use is associated with neurocognitive impairment, but no empirical study to date has assessed whether these difficulties extend to memory for future intentions (prospective memory).
Objectives The present study assessed prospective performance on a laboratory measure of prospective memory that closely represents the types of prospective memory tasks that actually occur in everyday life and provides an opportunity to investigate the different sorts of prospective memory failures that occur ("Virtual Week").
Materials and methods Twenty adults with confirmed history of methamphetamine use and dependence, currently engaged in rehabilitation and confirmed to be abstinent for an average period of 6 months, and 20 methamphetamine-naive participants were tested on Virtual Week. Various other aspects of cognitive function were also assessed, including retrospective memory and executive functioning.
Results Methamphetamine users were significantly impaired on Virtual Week, and these deficits did not vary as a function of specific prospective memory task demands. Of all the cognitive measures, cognitive inhibition shared greatest variance with group effects on the prospective memory measure.
Conclusions Prospective memory performance is sensitive to prior methamphetamine use even well into abstinence. Methamphetamine users experience generalized difficulties with prospective memory, suggesting that these deficits are likely to have important implications for day-to-day functioning.

Keywords Methamphetamine · Cognitive performance · Prospective memory impairment · Memory for intentions · Substance abuse

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Introduction

Methamphetamine is a highly addictive psychostimulant, with epidemic increases in use of this drug recorded globally (Meredith et al. 2005). Numerous studies have shown that methamphetamine disrupts neurotransmitter function and in particular the dopaminergic system, although changes in serotonergic, noradrenergic, and glutamatergic function are also observed (Meredith et al. 2005; Nordahl et al. 2003). The effects of methamphetamine on these neurotransmitters have been related to long-term neuronal damage. For instance, a positron emission tomography study by McCann et al. (1998) found that dopamine receptor density was significantly reduced in abstinent methamphetamine users, even though the drug users had an average length of abstinence of 3 years.

The dopaminergic system exhibits modulatory effects on many brain regions implicated in cognitive functioning, including frontostriatal and limbic structures (Cohen and Servan-Schreiber 1993), with some evidence suggesting that the orbitofrontal cortex may be particularly affected (see Meredith et al. 2005). It has been argued that these neuropathological changes underpin the neurocognitive

deficits associated with methamphetamine use in humans (Nordahl et al. 2003). Consistent with this possibility, in a recent meta-analysis of the neurocognitive effects of methamphetamine, Scott et al. (2007) reported significant impairment in several cognitive domains that are considered to impose demands on the integrity of these neural substrates, including retrospective memory, information processing speed, and executive operations such as inhibitory control.

The aim of the present study was to investigate whether these neurocognitive difficulties extend to *prospective* memory, which refers to memory for future intentions. Everyday prospective memory tasks include remembering to take medications and turn off appliances, and thus intact prospective memory function is crucial for maintaining health and safety and necessary for independent living. Importantly, deficits may be anticipated because this aspect of cognitive function imposes demands on many of the neural regions that are known to be affected by methamphetamine use. Further, prospective memory function is dependent on the integrity of other aspects of cognition and, in particular, retrospective memory (Cohen et al. 2001) and executive control (Craik 1986). Since both retrospective memory and executive functioning are disrupted in the context of methamphetamine use (Scott et al. 2007), prospective memory deficits may also be expected to arise as a consequence of deficits in each of these capacities.

Although no research to date has focused on the effects of methamphetamine on prospective memory, users of methylenedioxy-methamphetamine (MDMA, or ecstasy), a related compound that has similar neurotoxic effects, including damage to dopaminergic and serotonergic terminals and neuronal apoptosis (see Cadet et al. 2007), have been found to show prospective memory deficits, as indexed both via self-report (Heffernan et al. 2001; Rodgers et al. 2001) as well as via behavioral assessment (Rendell et al. 2007a; Zakzanis et al. 2003). In the study of Zakzanis et al. (2003), participants were asked to remember to ask for a belonging at the end of the test session, ask a specific question when an alarm sounded, and deliver a message at a specific point during testing. Results indicated that MDMA users were significantly less likely to remember to execute these delayed intentions relative to controls. Rendell et al. (2007a) found evidence for generalized prospective memory impairment in MDMA users who were tested using Virtual Week, the prospective memory measure which was also used in the present study. Rendell et al. (2007a) showed that MDMA users were significantly impaired on all prospective memory tasks and that these impairments remained after controlling for marijuana use, level of psychopathology, and sleep quality. Together, these findings of prospective memory impairments in users of MDMA, which is a form of amphetamine, therefore support a potential link between methamphetamine use and prospective memory.

The primary aim of the present study was therefore to provide the first behavioral assessment of prospective memory performance in former users of methamphetamine. As noted, this will be achieved using "Virtual Week"; This laboratory measure closely represents the types of prospective memory tasks that actually occur in everyday life and provides an opportunity to investigate the different sorts of prospective memory failures that occur (see Rendell and Craik 2000; Rendell et al. 2007a). Thus, by using Virtual Week, it will be possible to quantify the nature and magnitude of any prospective memory deficits associated with methamphetamine use. A secondary aim will be to broadly characterize the cognitive and clinical correlates of any observed difficulties in prospective memory function.

Materials and methods

Design

A mixed design with methamphetamine status (user, control) between participants and prospective memory task (regular, irregular, time check) within participants was used. These were the task distinctions that have generated the sharpest distinction in prospective memory performance in previous studies involving Virtual Week (Henry et al. 2007; Rendell and Craik 2000; Rendell et al. 2007a, b). The substantial within-group differences according to these task types shown in these studies are not of interest in the present study. Instead, the primary interest is in whether there is any evidence of an interaction between methamphetamine status and task type, i.e., is there any evidence that methamphetamine users have particular difficulties in specific aspects of prospective memory function. Therefore, within-group differences will not be reported unless there is significant interaction with methamphetamine status. The primary dependent variable of interest on Virtual Week was the proportion of correct responses on each of the prospective memory tasks. To more broadly characterize overall cognitive status, as well as to investigate potential cognitive correlates of any observed prospective memory difficulties, a number of other cognitive measures were also administered.

Participants

Twenty adults (60% male) with a confirmed history of methamphetamine dependence were recruited through the Commonwealth Rehabilitation Service (CRS Australia). A control group of 20 participants (60% male) with no self-reported history of substance abuse was also included in the study. All participants were reimbursed $12 for their research participation (approximately $10 USD).

To be included in the methamphetamine group, participants had to have a clinical diagnosis of methamphetamine dependence (DSM-IV, American Psychiatric Association 2000), no current or previous diagnoses of dependence on any other substances, and to be confirmed as currently abstinent. All participants in the methamphetamine group were in a residential drug rehabilitation program or had recently completed the program and were in a managed community-based program. Abstinence and routine drug testing were conditions of participating in these rehabilitation programs. The methamphetamine group had been in rehabilitation and abstinent for 3 to 8 months (M=5.90, SD=1.41), with the previous period of methamphetamine use ranging from 1 to 8 years (M=3.85, SD=2.16). Over this period, reported methamphetamine used varied from 2 to 5 g/week (M=3.60, SD=0.94). All details related to drug use, abstinence, and participation in rehabilitation were confirmed by the relevant case managers.

Exclusion criteria for all participants were past and present comorbid psychiatric condition and an identifiable neurological disorder. These were ruled out by CRS caseworkers who had access to the participant's medical and psychological records. Additional exclusion criteria were poor level of English and heavy alcohol use. The exclusion level for alcohol consumption was set at 28 units per week for men and 14 units for women, following guidelines set by the Australian National Health and Medical Research Council (2001). Approximately 100 people were considered for the methamphetamine group of which 80% failed to meet the inclusion criteria. Those considered for inclusion were all former users of methamphetamine; all had confirmed methamphetamine dependence, and all were in the rehabilitation programs already outlined. The two major reasons for exclusion were comorbid psychiatric illness or dependence on other substances.

Thus, although the methamphetamine group did tend to have used other illicit drugs, none had a history of dependency on any substance other than methamphetamine. Table 1 shows the frequency and duration of previous use of illicit drugs by the methamphetamine group. It can be seen that the group did tend to have used amphetamine (which was a relatively broad category that included MDMA) and cannabis, but only some had used cocaine and none reported using heroin. The control group did not report use of any of these illicit substances, but all consumed alcohol. The current use of alcohol by control group participants was ns=6, 11, 3, and 0 for 1–7, 8–14, 15–21, and 22–27 standard alcohol drinks per week. The methamphetamine group were currently not drinking (n=11) or drinking less than eight standard drinks per week (n=9). However, this group did previously use alcohol with ns=4, 4, 7, and 5 for 1–7, 8–14, 15–21, and 22–27 standard alcohol drinks per week.

Background measures

The Hospital Anxiety Depression Scale (HADS: Zigmond and Snaith 1983) was used to quantify levels of negative affect. The HADS is a 14-item self-report measure, frequently used in clinical practice and research, and reported to demonstrate good internal consistency and test–retest reliability (Crawford et al. 2001). The National Adult Reading Test (NART: Nelson 1982) is an oral reading test consisting of 50 words that violate grapheme–phoneme correspondence rules (e.g., chord), and is the most widely used formal method of estimating premorbid ability. NART performance correlates highly with IQ and is robust in the face of many neurological and psychiatric disorders (Crawford and Henry 2005).

Two measures were also used to index executive functioning. Phonemic fluency is one of the best validated measures of this construct, requiring self-initiated retrieval, information updating, and monitoring (Henry and Crawford 2004). In the present study, the letters F, A, and S were used, with participants given 1 min to produce as many words as possible beginning with each letter. The dependent measure was the total number of responses minus repetitions and inappropriate responses (i.e., proper nouns, the same word with a different suffix, or words that do not begin with the target letter).

The Hayling Sentence Completion Test (Burgess and Shallice 1997) was the second measure of executive

Table 1 Frequency and duration of substance use by participants in the methamphetamine (MA) group

	Frequency of use					Duration of use				
	Never or occasionally	Once a week	Once a fortnight	Once a month	>Once a month	Never or occasionally	<6 months	6–12 months	1–3 years	3 years or more
Amphetamine[a]	1	5	9	4	1	1	1		13	5
Cannabis	3	1	2	12	2	3	–	1	6	10
Cocaine	11	–	1	3	5	11	–		4	5
Heroin	20	–	–	–	–	20	–	–	–	–

[a] Amphetamine was a relatively broad category that included MDMA

functioning administered and is particularly sensitive to inhibitory failures. This test requires the participant to complete a sentence that has a word missing at the end. In section A, the word given must be congruent with the sentence. In section B, the word given must be incongruent with the sentence in every way. The Hayling has good convergent validity with other measures of cognitive inhibition (de Frias et al. 2006). Scaled scores were calculated using Burgess and Shallice's (1997) scoring criteria based on response latency and error responses, ranging from 1 (impaired) to 10 (very superior), with a score of 6 indicative of average ability.

Retrospective memory was assessed using the Rey Auditory Verbal Learning Test (AVLT, Rey 1964). Total recall from a five-trial presentation of a 15-word list was used to index verbal learning, while delayed recall was assessed by measuring the number of words from that original list that participants were able to remember 15 min later. Digits forward and digits backward (Wechsler 1997) were used to index short-term and working memory, respectively. In digits forward, a series of digits were read aloud, and the participant was required to recall these digits back in the original sequence. For digits backward, the participant was required to repeat the digits back but in the reverse order.

Prospective memory

Virtual Week was used as the laboratory measure of prospective memory. This study used a computerized version of Virtual Week that closely followed the original version (see Rendell and Craik 2000). Virtual Week is a board game, in which participants move a token around the board with the roll of a dice. The consecutive hours of the day people are typically awake are marked on the board, with each circuit of the board representing a day. As participants move the token around the board, they are required to make choices about daily activities and remember to carry out lifelike activities (prospective memory tasks). Participants access ten event cards each circuit (or each virtual day) that each provide three options of activities relevant to the virtual time of day. After making their selection, a dice rolling option is revealed, which could be roll an even number, roll a specific number, or roll any number before moving on. Each "day" of Virtual Week includes ten prospective memory tasks (four regular, four irregular, and two time-check tasks) and in this study participants completed three virtual days. Participants do not physically undertake the tasks; instead they click on a perform task button to display a list of tasks including distracters and then select the task from the list.

The four regular prospective memory tasks simulate the kinds of regular tasks that occur as one undertakes normal duties, two of which are time-based, *take asthma medication* at 11 A.M. and 9 P.M. (triggered by passing the 11 A.M. square and 9 P.M. square), and two are event-based, *take antibiotics* at breakfast and dinner (triggered by event cards featuring breakfast and dinner). The four irregular prospective memory tasks simulate the kinds of *occasional* tasks which occur in everyday life; again, two of these are time-based and two are event-based, examples are "drop dry cleaning in when shopping" (triggered by an event card featuring shopping) and "phone a plumber at 4 P.M." (triggered by passing the 4 P.M. square). Finally, the two time-check tasks require the participant to "break set" from the board game activity and monitor real time on the stop clock that was displayed prominently and indicate when a specified period of time has passed. Participants were asked to do a *lung test* on two occasions, when 2 min 30 s and 4 min 15 s was displayed on the stop clock. There is considerable evidence for the reliability (Henry et al. 2007; Rose et al. 2007) and validity of this measure (Henry et al. 2007; Kardiasmenos et al. 2008; Rendell and Craik 2000; Rendell et al. 2007b; Will et al. 2008).

Answers on Virtual Week were scored in the following four categories; *Correct* response indicated the target item was remembered at the correct time (correct time for the time-check task was within 10 s of the target time and for the other tasks it was before next roll of the dice); *little late* were after the correct time criterion but within 11–30 s on time-check task and on other tasks, those made before the next time square for time-based tasks and before the next event card for event-based tasks; *lot late* responses were those later than *little late* criterion but before the end of the virtual day (circuit of board). *Missed* responses indicated a failure to respond.

Procedure

This study was approved by the Human Research Ethics Committee of the Australian Catholic University, and the Commonwealth Rehabilitation Service Australia Research Committee. After obtaining written informed consent, participants were tested individually in a single session lasting up to 3 h, with breaks at appropriate times to prevent fatigue. Participants first completed the brief demographic questionnaire, followed by the NART and the HADS. The order of presentation of the remaining measures (which included several measures unrelated to the current research) was counterbalanced to minimize any potential fatigue or order effects.

Results

The background details of participants are shown in Table 2. In addition to being matched on gender (both groups 60%

Table 2 Background characteristics of the methamphetamine (MA) and control groups

	MA group, n=20		Control group, n=20		Inferential statistics (df=38)	
	M	SD	M	SD	t	p
Age	27.50	5.21	28.20	5.00	0.43	0.667
Level of English[a]	1.40	0.60	1.45	0.61	0.26	0.794
Years of education	11.65	1.82	12.65	2.48	1.46	0.153
HADS Psychopathology[b]	9.70	4.77	8.15	4.41	1.07	0.292
Self-rated health[c]	2.10	0.79	2.05	0.89	0.19	0.852
Self-rated sleep[c]	2.40	0.88	2.35	0.93	0.17	0.863
NART premorbid IQ[d]	105.15	10.15	109.40	10.86	1.28	0.209
Executive functioning						
Fluency	36.80	11.23	48.25	17.57	2.46	0.019
Hayling	3.20	1.44	5.55	0.76	6.47	<0.001
Retrospective memory						
Verbal learning[e]	42.80	6.40	49.40	7.45	3.01	0.005
Delayed recall[e]	9.45	1. 99	10.90	2.19	2.04	0.049
Digit span forward	9.05	2.46	11.25	2.12	3.03	0.004
Digit span backward	6.25	2.38	7.90	2.13	2.31	0.026

[a] Participants were asked to self-rate their English-language level on a five-point Likert scale: 1 = excellent; 2 = very good, 3 = good; 4 = not very good; 5 = poor
[b] Total score on the HADS measure of depression and anxiety
[c] Participants were asked to self-rate sleep and health "over the last month" on a five-point Likert scale where 1 = excellent; 2 = very good; 3 = good; 4 = not very good; 5 = poor
[d] WAIS-R full-scale IQ score as predicted from the number of errors made on the NART
[e] Verbal learning was the total number of words recalled over five trials on the ALVT and delayed recall was the number of words recalled after 15 min

male), the methamphetamine and control groups did not differ significantly with regard to age, years of education, self-rated English-language level, premorbid IQ, depression and anxiety or self-rated health, and sleep over the past month.

The mean proportion of correct responses for the two groups on three types of prospective memory tasks is shown in Table 3. A mixed 2×3 analysis of variance did not reveal any significant interaction effect, $F(2, 76)=0.24$, MSE=0.02, $p=0.791$, $\eta^2=0.01$, but the main effect, group, was significant, $F(2, 76)=48.96$, MSE=0.04, $p<0.001$, $\eta^2=0.56$, indicating that participants in the methamphetamine groups made a significantly lower proportion of correct responses (M=0.29, SD=0.19) than controls (M=0.56, SD=0.24), with Cohen's d=1.25 (Cohen (1988) defines effect sizes of 0.2 as small, 0.5 as medium, and 0.8 as large). Further analysis of another task distinction, event- versus time-based, also revealed no differential effect of methamphetamine group on these different types of prospective memory task (all ps>0.10). Thus, the methamphetamine group presented with an undifferentiated profile of impairment across the different types of prospective memory task.

Table 3 also reports the proportion of correct responses and different types of error responses made for the methamphetamine and control groups. It can be seen that, for both groups, the majority of errors on the regular and irregular tasks are *missed* responses. For the time-check

Table 3 Mean proportions of correct responses and different types of error on Virtual Week for the methamphetamine (MA) and control groups as a function of prospective memory task type

Measure	Regular task				Irregular task				Time-check task			
	MA		Control		MA		Control		MA		Control	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Correct	0.43	0.13	0.68	0.13	0.35	0.12	0.63	0.20	0.09	0.11	0.38	0.27
Little late	0.07	0.06	0.13	0.09	0.06	0.09	0.08	0.06	0.20	0.18	0.28	0.18
Lot late	0.11	0.09	0.05	0.06	0.10	0.10	0.11	0.09	0.27	0.22	0.16	0.17
Missed	0.39	0.13	0.14	0.12	0.49	0.19	0.19	0.17	0.44	0.22	0.18	0.14

task, however, while for the methamphetamine (but not the control) group a substantial proportion of errors are attributable to *missed* responses, the predominant source of error for both groups on the time-check task is the late responses. In analysis of the proportion of missed responses, group did not significantly interact with prospective memory task, $F(2, 76)=0.39$, MSE=0.02, $p=0.678$, $\eta^2=0.010$, but group was a significant main effect $F(1, 38)=57.86$, MSE=0.04, $p<0.001$, $\eta^2=0.60$. Participants in the methamphetamine group missed significantly more responses ($M=0.44$, SD=0.18) than the controls ($M=0.17$ SD=0.15, Cohen's $d=1.70$).

Separate analyses of little late and lot late revealed contrasting group effects. In both analyses, group was a significant main effect (*little late*: $F(1, 38)=6.42$, MSE=0.02, $p=0.016$, $\eta^2=0.145$; *lot late*: $F(1, 38)=5.61$, MSE=0.02, $p=0.023$, $\eta^2=0.129$) and in both analyses group did not significantly interact with prospective memory task ($ps>0.10$). The methamphetamine group made significantly more *lot late* responses ($M=0.16$, SD=0.16) than did the control group ($M=0.11$, SD=0.12), $d=0.35$, but significantly fewer *little late* responses ($M=0.11$, SD=0.13) than the control ($M=0.17$, SD=0.15), $d=0.43$.

Correlations between proportion correct on prospective memory tasks in Virtual Week with self-ratings of health and sleep and measures of alcohol use were not significant for either the methamphetamine or control group. The correlations of prospective memory task accuracy were also not significantly correlated with cannabis and amphetamine use by the methamphetamine group. These were the only correlations calculated for prospective memory task accuracy and substance abuse. As reported previously, most participants in the methamphetamine group did report use of cannabis and amphetamines but only nine reported using cocaine and none reported using heroin. The control group did not report use of any of these substances.

While the use of analysis of covariance (ANCOVA) in non-randomized designs has been subject to some debate, it has been suggested that this methodology may be useful (despite non-random assignment) in the context of exploration of a dataset to understand patterns of shared variance (Huitema 1980; Miller and Chapman 2001). Thus, to assess whether variance in performance on the prospective memory measure was shared with variance in performance on other cognitive tests, a series of ANCOVAs were conducted with the between-participants variables of *group* (methamphetamine, control) and prospective memory task (regular, irregular, time check) with proportion correct as the dependent variable and one of the following variables entered as a covariate: fluency, Hayling, AVLT total, digit span forward, or digit span backwards. The group effects remained significant (all $p<0.05$) when covarying for each of these variables. However, of interest was how entry of each of these covariates impacted on the main effect size for group.

The group effect size (η^2) for proportion correct on the prospective memory tasks was substantially reduced for Hayling, a measure of cognitive inhibition (η^2 was reduced from 0.56 to 0.29, but there was little change in this group effect size for the other measures: 0.58 (fluency), 0.51 (AVLT total), 0.51 (digit span forward), and 0.55 (digit span backwards). Cognitive inhibition appeared to be the variable that shared greatest variance with group effects on the prospective memory measure.

Discussion

The present results indicate that methamphetamine use is associated with significantly increased prospective memory difficulties, that the magnitude of this deficit does not vary as a function of task type, and that these deficits are not simply secondary to the effects of other illicit drug use. Further, prospective memory impairment was observed in a methamphetamine group that had been abstinent on average for 6 months, providing further evidence that the neurocognitive difficulties associated with use of this drug are not transitory in nature. The present results are therefore important, providing the first behavioral evidence of consistent deficits in prospective memory function in users of methamphetamine. Further, it is noteworthy that these difficulties exactly parallel the impairment previously reported in the context of MDMA use (Rendell et al. 2007a). Thus, as was observed in the present study, MDMA use was associated with a relatively *generalized* negative effect on prospective memory function.

Analysis of the pattern of error responses on Virtual Week revealed that failure to respond was the most common type of error made by both groups but that across all tasks the methamphetamine group missed significantly more responses than the control group. Further analysis of both types of late responses (little or lot late) showed that the methamphetamine group significantly are less often a "little late" and more often "lot late." Qualitative observations suggest that retrospective memory failures are not sufficient to account for the magnitude of the prospective memory impairment observed. Specifically, the regular tasks in Virtual Week impose only minimal demands on retrospective memory and yet were substantially impaired.

These data have potentially important implications for rehabilitative practice. Common forms of treatment for methamphetamine dependence include cognitive–behavioral therapy and motivational enhancement. These, as well as many other interventions that target this particular population, impose considerable demands on the need for future-oriented goal-directed behavior such as making plans and remembering to carry out tasks outside the therapy session. The effectiveness of such treatments is therefore at least partially

contingent on the client's ability to implement delayed intentions. The identification of a generalized level of prospective memory impairment in the present study indicates that treatments such as these may be experienced as relatively more challenging for this particular population. Consequently, an important consideration for rehabilitative practice is the level of prospective memory demands implicit in the treatment protocol.

As well as quantifying the nature and magnitude of prospective memory difficulties associated with methamphetamine use, this study also aimed to identify the cognitive correlates of any observed group differences in prospective memory function. Firstly, and consistent with considerable prior research (see Meredith et al. 2005; Scott et al. 2007), the results indicated that methamphetamine users were significantly impaired on measures of retrospective memory and executive functioning. However, of particular interest was the finding that, after covarying for each of these cognitive measures, group effects on Virtual Week remained significant. These data therefore also suggest that the prospective memory difficulties observed in the methamphetamine group primarily reflect a breakdown in the prospective component of the task and not secondary task demands.

Nevertheless, there was evidence of some overlap between prospective memory task performance and other facets of cognitive functioning and in particular cognitive inhibition. As noted previously, executive function failures have been found to contribute to prospective memory difficulties in other populations (e.g., Kliegel et al. 2003; Kopp and Thöne-Otto 2003; Martin et al. 2003). With respect to the specific role of cognitive inhibition, Kliegel et al. (2003) noted that prospective memory tasks require inhibition to avoid distraction from irrelevant items.

In the case of Virtual Week, prospective memory tasks involve switching from the ongoing task (the board game activity) to the prospective memory task at hand, which involves the need to inhibit the tendency to proceed with the ongoing task alone. It is probable that performance of the intended prospective memory action therefore requires inhibition of the prepotent response tendency, which in the case of Virtual Week is to continue with the game activity. Consequently, it may be that deficits in inhibitory control contribute to prospective memory difficulties in methamphetamine users. However, the fact that the current study is cross-sectional clearly limits the causal conclusions that can be drawn; longitudinal work would represent an important supplement to the current findings.

Another limitation of the present study was the size of the clinical sample, which was relatively small. Thus, although the power to detect large group differences of the type identified on many of the dependent measures on Virtual Week was high, the power to detect more subtle main and interaction effects was low. Consequently, the present results do not provide as sensitive an assessment of prospective memory difficulties in this population as would be optimal. In addition, it is difficult to gauge how representative the small group of methamphetamine participants included in the present study is of the larger population of adults with a history of methamphetamine abuse. However, it is important to note that the relatively small group of former methamphetamine users was attributable to the application of very stringent inclusion criteria. Thus, a great majority of potential participants with a history of methamphetamine use were excluded due to complicating factors such as heavy use of other illicit substances, dependency on other substances, comorbid psychiatric diagnoses, lack of access to the third-party information needed to confirm abstinence, and poor English. This high level of control over other factors, although resulting in a smaller sample, did increase the quality of the current findings. However, while a strength of the present study was the stringent drug testing of the methamphetamine group, a limitation was the use of self-report assessment to confirm an absence of substance abuse in the control group. Consequently, the possibility of controls abusing recreational drugs cannot be definitively ruled out. Thus, although the very large group effects that were identified suggest that the two groups did differ with regard to drug history status, clearly in future research it would be optimal to also use drug testing to confirm abstinent status in the control group.

In summary, the present results provide the first empirical evidence of generalized prospective memory impairment following methamphetamine use. The absence of an interaction between group status and prospective memory task provides evidence for a pervasive prospective memory deficit in the context of methamphetamine use. Further research is needed to delineate the mechanisms underpinning this impairment.

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