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Original Investigation

Visuospatial memory impairments in users of MDMA ('ecstasy')

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Abstract

Rationale Previous studies have presented conflicting findings regarding visuospatial span deficits in MDMA ('ecstasy') users, possibly attributable to a lack of distinction between simple visuospatial span and visuospatial working memory span. Both draw upon central executive

processing, while the latter also involves concurrent goal-orientated visuospatial processing.

Objectives This study compared visuospatial working memory span for MDMA users and controls. An additional concurrent task also loading on the central executive tested for inter-group differences related to central executive workload.

Method MDMA user group (25 current users, 10 previous users and 18 non-users) was between-participants, and dual task condition (concurrent alphabetic generation, random letter generation, and no dual task) was within-participants. The visuospatial working memory task required participants to serially recall a spatial sequence while simultaneously completing a visual judgement task, and was completed on its own and under dual task conditions.

Results Overall, non-users performed significantly better than both MDMA user groups. However, contrary to expectation, the performance decrement among users was no worse with concurrent random generation than under control conditions. Analyses controlling for background variables and the use of other drugs in the previous 3 months showed that the main effect of MDMA remained significant following control for intelligence, alcohol, amphetamines and cocaine, among other potential confounds. Unclear results were found following control for cannabis use.

Conclusions The MDMA users experienced deficits in visuospatial working memory span. The lack of interaction between dual task condition and user group may be due to inter-group differences in central executive utilisation under different task conditions.

Keywords Visuospatial memory impairment - MDMA ('ecstasy') users

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Previous research concerning visuospatial memory amongst users of 3,4-

methylenedioxymethamphetamine (generally known as MDMA or 'ecstasy') has produced an apparently contradictory set of results. One common testing procedure is to use either wooden blocks or computer-generated squares laid out in a grid format, with a short series of these being highlighted in sequence, either by being tapped by the researcher or illuminated on the screen. The participant is then required to repeat this sequence by whatever means appropriate (e.g. block tapping, mouse clicking, etc.). Verkes et al. (*2001*) found that both heavy and moderate users of MDMA performed worse on this task than controls who had generally used the same range of other drugs. However, Gouzoulis-Mayfrank et al. (*2000*) found no significant difference between MDMA users and two control groups, respectively, who either had no history of regular drug use or whose cannabis use matched that of the MDMA users. On a similar task, Morgan (*1998*) found no significant difference in performance between MDMA users and two control groups, respectively, who either had no history of illicit drug use or whose overall pattern of polydrug use matched that of the MDMA users except for MDMA use.

One recent variation on the illuminated-squares procedure presented participants with a computer image for 3 s of a house with 12 windows, 5 of which were illuminated. After a 7s delay, a second house appeared, also having 5 of its 12 windows illuminated. Each participant's task was to identify which 2 illuminated windows were common to both houses. MDMA users made significantly more errors than controls with a history of using other drugs, with the error rate of MDMA users being dose related (Fox et al. *2001*). It may be argued that the closer relationship of this form of presentation to everyday experience may have made the task more amenable to participants than the presentation of an abstract grid.

An innovative search task was employed by Fox et al. (*2002*), requiring participants to find a blue token hidden in one of a display of boxes.

Once found in a particular box, that box would not be used again to hide the token, so that returning to this box in a subsequent trial would provide a measure of error. Returning to a box that had previously been found to be empty within the same trial provided a second error measure. MDMA users performed significantly worse on both of these measures than controls with a history of using other illicit drugs. However, no difference was found on a spatial recognition task involving a computerised display of boxes. Spatial recognition involving the use of grids has also failed to reveal differences between MDMA users and controls (McCann et al. *1999*).

The contradictory pattern of results described above may be seen as a justification in itself for further research into the possible effects of MDMA use upon visuospatial memory. However, some reflection upon the pattern is necessary in order to determine the most appropriate direction for further research to take. It may be argued that the majority of tasks employed so far predominantly requires the storage of spatial information, with a minimum of additional processing towards some other specified goal being required. One exception to this would be the search task employed by Fox et al. (*2002*), which required the continual updating of search related information and revealed poorer performance by MDMA users than controls. The distinction between tasks requiring predominantly storage and those requiring storage plus explicit goal-orientated processing is generally regarded as differentiating measures of simple short-term memory span from measures of working memory (see Miyake et al. *2001* for further discussion of this). Miyake et al. (*2001*) also demonstrated that with visuospatial information the distinction between short-term and working memory could, for practical purposes, be abolished, and that the new combined visuospatial memory construct drew very heavily upon central executive capacity. It is worth noting that the updating required in the search task employed by Fox et al. (*2002*) might reasonably be assumed to draw upon central executive capacity

(Miyake et al. *2000*), and that the deficits observed may be seen to raise questions of safety regarding the performance by MDMA users of everyday tasks (examples include driving and operating machinery) where similar updating would be required.

Wareing et al. (*2000*) demonstrated that central executive functioning was impaired in current and former heavy MDMA users (mean estimated lifetime use 1000 tablets or more), although relatively minor impairments were subsequently found in light to moderate users (mean estimated lifetime usage 583 tablets or less, Wareing et al. *2002*). Nevertheless, it is possible that deficits in visuospatial memory in MDMA users may be linked to impairments in central executive functioning, so that tasks with minimal additional processing requirements may not reliably elicit impaired performance. Where impairments are found on such tasks, this could result from an interaction of participant characteristics (such as lifetime experience of MDMA use) and specific task characteristics. It is worth noting that, for the illuminated-blocks task, Verkes et al. (*2001*) reported a mean lifetime exposure of 169 tablets for their moderate MDMA users, with a corresponding mean of 741 for their heavy users. By comparison, the studies finding no impairment for MDMA users reported estimated lifetime means of 93.4 tablets (Gouzoulis-Mayfrank et al. *2000*) and 35.6 tablets (Morgan *1998*), respectively. Even allowing for the approximate nature of such reports, the issue of extent of MDMA exposure would seem to require serious consideration.

Building on our earlier work demonstrating central executive impairments in MDMA users (Wareing et al. *2000*), the present study explored the role of the central executive in visuospatial working memory in groups of both current MDMA users, and former regular users who have been abstinent for at least 6 months. This was done by utilising a task requiring storage plus processing of visuospatial information (Fisk et al. *2003*), whilst requiring participants to perform a

second concurrent task (random letter generation) believed to draw upon central executive capacity (Baddeley *1996*). It was predicted that both MDMA user groups would show poorer visuospatial working memory spans than non-using controls in all task conditions, and that this difference would be greatest in a dual task condition requiring concurrent random letter generation (i.e. a group by task condition interaction).

Methods

Design

A mixed design was utilised with user group (current, previous, and non-user) between-participants and dual task (random generation, alphabetic generation, and control-no dual task) within-participants. The alphabetic generation condition was included to control for any inter-group differences in phonological loop functioning. The dependent variable was visuospatial working memory span as measured by the procedure described below. Measures of background variables such as age, fluid intelligence, and simple visuospatial span were taken and subsequently treated as covariates. The test of simple visuospatial span (i.e. not requiring any concurrent goal-orientated processing) was included to control for any inter-group differences in perceptual and storage processes. Measures of other drug use were also recorded for subsequent use as covariates.

Participants

Recruitment initially took place from an undergraduate student population with participants being contacted through advertisements. Further recruitment then took place using the snowballing technique. All participants indicated that they had not used any illegal drugs for 7 days prior to testing. There were 25 current MDMA users (11 male, 14 female), 10 former MDMA users (6 male, 4 female), and 18 non-users (6 male, 12 female) recruited for the study. Details of participants' ages, other background variables, and history of MDMA use are shown in Table 1, whilst details of other drug use are shown in Table 2. The requirement for inclusion in the former users group was that MDMA should not have been used for at least 6 months prior to testing. The only prescribed medication received by MDMA users in either group in the 10 days prior to testing was either the contraceptive pill or insulin for diabetes. One control participant had taken medication for migraine in the 10 days prior to testing, while two others listed medication that could not subsequently be traced in standard reference sources. In terms of occupation, students formed the majority of the sample with 15 in the current user group (two postgraduates), 3 in the former user group (one postgraduate), and 14 in the non-user group (two postgraduates).

Table 1 Measures of background variables and details of MDMA ('ecstasy') use

	Current user		Former user		Non-user	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Background variables						
Age (years)	21.92	2.80	28.00	5.64	25.22	8.00
Education (years)	14.82	2.82	13.70	2.50	15.69	2.41

Raven's D Score (max. 12)	8.92	2.02	7.89	2.26	9.67	1.50
Raven's E Score (max. 12)	5.76	3.02	4.11	2.52	5.89	3.16
Spatial span	4.60	1.04	4.00	1.63	4.83	1.42
Details of MDMA use						
Length of use (weeks)	245.68	149.96	229.00	65.71	–	–
Weeks since last use	3.40	2.87	107.93	80.80	–	–
Total tablets consumed	655.58	805.50	469.20	414.96	–	–

Table 2 Number and (%) of participants in each MDMA ('ecstasy') user group indicating use of each drug in the previous 3 months

Drug	Current MDMA users	Former MDMA users	Non-users
Alcohol	23 (92.0)	6 (60.0)	16 (88.9)
Amphetamine	8 (32.0)	3 (30.0)	1 (5.6)
Cannabis	22 (88.0)	7 (70.0)	5 (27.8)
Cocaine	13 (52.0)	2 (20.0)	1 (5.6)
LSD	2 (8.0)	2 (20.0)	0 (–)
Mushrooms[a]	3 (12.0)	1 (10.0)	1 (5.6)
Poppers	10 (40.0)	1 (10.0)	1 (5.6)
Tobacco	14 (56.0)	8 (80.0)	5 (27.8)

[a]Hallucinogenic mushrooms

Measures

Demographic characteristics and drug use

A background questionnaire recorded the use of MDMA, with the frequency of other drug use in the previous 3 months being measured using a 4-point ordinal scale (never, occasionally, frequently, always). Details of age, educational record, and various other lifestyle variables including relevant aspects of health were also recorded. Fluid intelligence was measured through Raven's progressive matrices (sets D and E) (Raven et al. *1998*).

Simple visuopatial span task

The simple visuopatial span task required participants to recall the position of target cells highlighted with a pattern comprising two rows of the letter 'X' within a four by four matrix of cells shown on a computer screen. Each highlighted cell was displayed for 1.25 s after which the cell went blank and the next target cell was highlighted. The task commenced with three consecutive matrices with one target cell in each highlighted (i.e. one cell per trial). For the next set of three trials, two cells were highlighted per trial. On each subsequent set of three trials the number of cells highlighted per trial increased by one until the participant failed on at least two of the three trials. After each matrix presentation, the participant responded by marking the position of the highlighted cell(s) in the order in which they occurred on a hard copy of a blank matrix. The number of highlighted cells in the last set with two of the three trials answered correctly constitutes the participant's simple visuospatial span, and as a measure of ability to encode a spatial sequence, this may be deemed comparable to measures from Corsi's blocks test.

Visuospatial working memory task

Participants were presented on screen with a four-by-four matrix containing five highlighted cells for 3 s. This task commences with three trials with one matrix being displayed. On the next three trials two matrices were presented sequentially per trial. On subsequent sets of three trials the number of matrices presented sequentially per trial increased progressively by one per set up to a maximum of six. In each matrix, four of the highlighted cells were filled with a pattern comprising two rows of the letter 'X', with the remaining cell highlighted with a pattern comprising two rows of the digit '0'. The participant was required to remember the position of the latter cell while at the same time indicating (by pointing) whether the number of cells highlighted had been greater in the top half of the matrix than in the bottom half. After all of the matrices in a particular trial had been presented, the participant was required to indicate the sequential positions of the cells highlighted with the digit '0' using a hard copy of a blank matrix. The task generated a span score corresponding to the maximum number of highlighted cells recalled in the order presented. This level had to be achieved in at least two of the three trials at a given level.

This visuospatial working memory task is analogous to verbal working memory measures such as computation span and reading span in that it requires the concurrent processing and storage of information. In addition, it generates a span score that can be compared with spatial span measures in the same way that measures of verbal working memory, such as reading and computation span, can be compared with word and digit span.

The visuospatial working memory task was repeated three times. Each participant performed it on its own as described above, with concurrent alphabetic generation, and with concurrent random letter generation. In these latter variations, each time the participant performed the pointing

sub-task s/he was also required to speak aloud a letter. In the alphabetic condition, the sequence produced was to be alphabetically ordered. In the random generation condition, the participant was asked to try to produce the sequence in a random fashion, avoiding alphabetically ordered pairs and established sequences such as CIA or BBC. The participant was also asked to try to produce each letter with equal frequency. The order in which the three conditions were experienced was randomised.

Procedure

The measures were administered under controlled laboratory conditions. Participants were informed about the general purpose of the study and the types of measures that would be administered before consent was obtained. Confidentiality was assured and participants' personal details were stored separately from the other data generated by them. Written consent was obtained from each participant. A number of other measures were administered which lie outside the scope of the present paper (i.e. not concerning visuospatial working memory) for which the results are to be, or have been, reported elsewhere (for example Wareing et al. *2002*). After all of the measures were administered, participants were debriefed, paid £15 (pounds sterling) in store vouchers, and provided with drug education leaflets. The study was approved by the ethics committees of Liverpool John Moores University and the Psychology Unit of Edge Hill College, and was administered in accordance with the ethics guidelines of the British Psychological Society.

Results

Descriptive analyses and analytic strategy

Table 3 shows the mean visuospatial working memory span scores for the MDMA user groups and the non-MDMA users. As predicted, both user groups performed less well than the non-users. However, it had been anticipated that the performance deficits of users would be at its greatest under dual-task conditions requiring random letter generation. In fact, the largest inter-group differences occurred in the control condition with no dual task, with the smallest occurring in the random generation condition.

Table 3 Mean visuospatial working memory spans for MDMA ('ecstasy') users and non-users

	Current user		Former user		Non-user	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Control (no dual task)	2.88	1.27	2.20	1.03	4.00	1.24
Alphabetic generation	2.68	1.52	2.30	1.25	3.56	1.20
Random generation	2.16	1.46	2.40	1.43	2.78	1.17
Overall mean and SD	2.57	1.17	2.30	0.88	3.44	1.01

Where possible, the results in Table 3 were analysed using mixed between-within-participants ANCOVAs, using measures of background variables and other drug use as covariates. Student Newman-Kuels pairwise comparisons for non-users versus current and former users respectively were conducted using a Bonferroni adjusted α=0.025, and were evaluated as one tailed. Where there were insufficient numbers of users of a drug for a meaningful ANCOVA to be performed, a series of

mixed between-within-participants ANOVAs were conducted, excluding the users of each such drug in turn.

Background variables as covariates

When the measures of age and years of education shown in Table 1 were taken as covariates, there was a significant between-participants main effect for group ($F_{2,48}$=4.22, P=0.020, partial η^2=0.15), with the pairwise comparisons revealing that both user groups performed significantly worse than the non-users (P=0.017 and 0.006 for current and previous users, respectively). The within-participants effect of dual task condition was non-significant (F<1). Further tests revealed that homogeneity of regression was achieved for both age and years of education. Specifically, the group by covariate interaction was non-significant, with $F_{2,47}$=1.53 (P>0.05) with respect to age, and F<1 for years of education.

The main effect of group remained significant when the two measures of fluid intelligence were taken as covariates ($F_{2,47}$=3.27, P=0.047, partial η^2=0.122). Pairwise comparisons showed that the performance of the current users remained significantly worse than that of the non-users (P=0.011). Whilst the performance of the previous users was still worse than that of the controls, the difference between these two groups was now narrowly non-significant (P=0.032). The within-participants main effect of dual task condition also achieved significance ($F_{2,94}$=3.122, P=0.049, partial η^2=0.062). Pairwise comparisons between the three task conditions (Bonferroni adjusted α=0.017 for three one-tailed comparisons) revealed that performance in the random generation condition was significantly worse than in the control condition (P=0.002), with the other comparisons not being significant.

Homogeneity of regression was achieved for both intelligence measures with the groups by covariate interactions yielding $F_{2,46}$=1.11 (P>0.05) for the Ravens D scores and F<1 for the Ravens E scores.

Unfortunately, ANCOVA with simple visuospatial span as a covariate failed to achieve homogeneity of regression, with the group by covariate interaction yielding $F_{2,47}$=4.74 (P=0.013). However, a one-way ANOVA failed to show any significant inter-group differences for simple visuospatial span ($F_{2,50}$=1.34, P>0.05). It is, therefore, unlikely that differences in the perceptual and storage processes for visuospatial material contributed to the observed differences in visuospatial working memory.

Measures of other drug use as covariates

The details of other drugs used in the 3 months prior to testing, shown in Table 2, indicate that the use of such drugs was more common amongst both MDMA user groups than among the non-MDMA users. Cannabis use as a covariate reduced the inter-group differences in visuospatial working memory span to being narrowly non-significant ($F_{2,49}$=3.02, P=0.058, partial η^2=0.110), with pairwise comparisons showing non-users still performing significantly better than former users (P=0.012), whilst only marginally failing to outperform current users (P=0.026). The within-participants main effect for dual task condition was non-significant ($F_{2,98}$=1.75, P>0.05). Homogeneity of regression was achieved with the group by covariate interaction yielding F<1. Given the marginal nature of these ANCOVA results for MDMA user group, and the argument put forward by some researchers that some cognitive deficits attributed to MDMA may really be due to cannabis (Croft et al. *2001*; Simon and Mattick *2002*), it was decided to re-examine the role of

cannabis as a covariate by combining both of the MDMA user groups. This restored the main effect for MDMA user group ($F_{1,50}$=5.64, P=0.021, partial η^2=0.101). The within-participants main effect for dual task condition now approached significance ($F_{2,100}$=2.78, P=0.067, partial η^2=0.053). Homogeneity of regression was once again achieved with F<1 for the group by covariate interaction. However, for both ANCOVAs with cannabis, the test for homogeneity of regression may have been weakened by all of the MDMA non-users falling into the categories of 'never' or 'occasionally', in contrast to the broader spread of frequency in the user groups.

When alcohol and tobacco use in the previous 3 months were treated as covariates, the main effect across the three user groups remained significant ($F_{2,48}$=3.69, P=0.032, partial η^2=0.133). The performance of both MDMA user groups was significantly worse than that of the non-MDMA users (P=0.008 and P=0.017 for current and previous users respectively). The main effect for dual task condition was not significant (F<1). Homogeneity of regression was achieved for both covariates, with the group by covariate interaction yielding F<1 in both cases.

There were insufficient numbers of amphetamine, cocaine, LSD, 'poppers' and hallucinogenic mushrooms users among the non-MDMA user group to conduct a meaningful ANCOVA. A mixed between-within-participants ANOVA was, therefore, repeated five times, each time excluding all users of the particular other drug in question. In all cases, the main effect of MDMA user group remained statistically significant, and pairwise comparisons showed that non-MDMA users performed significantly better than both user groups, with the exception of amphetamines where the difference between non-users and current users failed to reach significance. These results are shown in Table 4.

Table 4 Results of the analyses of variance performed with the exclusion of users of particular drugs

Drug for which users were excluded	*F* ratio, *P* value, and partial eta squared	Pairwise comparisons[a]
Amphetamine	$F_{(2,38)}=3.26$, $P=0.050$	Former V non-users $P=0.012$
	Partial $\eta^2=0.146$	Current V non-users $P=0.051$
Cocaine	$F_{(2,34)}=3.63$, $P=0.037$	Former V non-users $P=0.017$
	Partial $\eta^2=0.176$	Current V non-users $P=0.016$
Poppers	$F_{(2,38)}=7.28$, $P=0.002$	Former V non-users $P=0.006$
	Partial $\eta^2=0.277$	Current V non-users $P<0.000$
Mushrooms[b]	$F_{(2,45)}=5.67$, $P=0.006$	Former V non-users $P=0.011$
	Partial $\eta^2=0.201$	Current V non-users $P=0.001$
LSD	$F_{(2,46)}=4.04$, $P=0.024$	Former V non-users $P=0.013$
	Partial $\eta^2=0.149$	Current V non-users $P=0.009$

[a]Non-users showed larger visuospatial working memory spans than either user group in each comparison, with only 1 of the 10 comparisons reported not reaching significance at the revised α=0.025

[b]Hallucinogenic mushrooms

Discussion

The results of this study show that current users of MDMA demonstrated a significantly diminished visuospatial working memory span in comparison with non-users with no experience of the drug, while controlling for age, years of education, fluid intelligence, and the frequency of use of alcohol, tobacco, cocaine, poppers, hallucinogenic mushrooms, and LSD in the 3 months prior to testing. The comparison controlling for cannabis only marginally failed to achieve significance, whilst the comparison controlling for amphetamine showed a trend towards significance. Former users of MDMA who had abstained from using the drug for at least 6 months prior to testing showed a significantly diminished visuospatial working memory span in comparison with non-users while controlling for age, years of education, and the use of cannabis, alcohol, tobacco, amphetamines, cocaine, poppers, hallucinogenic mushrooms, and LSD in the 3 months prior to testing.

Given the unclear picture in the existing literature concerning visuospatial memory performance among MDMA users, these findings suggest that deficits in the handling of such information may be more readily detected by tasks requiring storage plus goal-orientated processing rather than tasks predominantly requiring storage. They also suggest impaired central executive functioning amongst the MDMA

users in comparison with the controls, given the pervasive involvement of the central executive in the storage and processing of visuospatial information (Miyake et al. *2001*). In terms of neuroanatomy, visuospatial working memory has been associated with a number of right hemisphere locations (e.g. posterior parietal and anterior occipital lobes; Smith and Jonides *1998*), whilst domain-free central executive processes have been associated bilaterally with pre-frontal cortex (Hartley and Speer *2000*). Our results suggest that the MDMA users studied may be functionally compromised in relation to one or more of these brain areas.

The question of a causal relationship between MDMA use and impaired cognitive performance is a matter of some controversy. There is evidence of neurotoxic damage in humans (McCann et al. *1998*; Reneman et al. *2002*) which would provide a potential causal mechanism for such impairments. However, opponents of this view argue that nearly all of the MDMA users tested have been polydrug users, and that consequent interactions between the drugs used, compounded by lifestyle factors, may be responsible for the deficits reported (Cole et al. *2002*). Like many other papers reporting impairments amongst MDMA users, this present paper does not directly address the question of a causal mechanism for the impairments demonstrated. What may be concluded is that this sample of MDMA users, for whom the use of alcohol, cannabis and tobacco were also relatively prevalent, were characterised by an impaired visuospatial working memory span. This impairment may be looked at alongside other areas of impairment in similar samples of MDMA users, such as verbal learning and memory, and abstract logical thinking (Gouzoulis-Mayfrank et al. *2000*). The diminished visuospatial working memory span in the former users of MDMA in this present study who had been abstinent from it for at least 6 months raises the possibility of long-term impairments arising within the population of MDMA polydrug users through whatever mechanism. Given the importance of visuospatial working memory in everyday tasks, such as driving and operating

machinery, these findings have potential health and safety implications for the general public. This is not the first study of such a sample to show deficits in cognitive performance persisting beyond 6 months since the last use of MDMA. Wareing et al. (*2000*) reported persisting central executive deficits using random letter generation, whilst Morgan et al. (*2002*) reported persisting deficits in episodic memory using the Rivermead Behavioural Memory Test. Questions concerning the time course and reversibility or otherwise of cognitive impairments can only be addressed effectively through longitudinal methodology, and the present authors are currently piloting such a study.

The absence of the predicted interaction between MDMA user group and task condition requires some explanation and further investigation. Instead of the largest differences in visuospatial working memory span between non-users and both user groups being found in the random generation condition, this condition actually showed the smallest differences. Performance progressively declined for all groups through the control and alphabetic generation conditions, with the control condition showing the largest differences between non-users and both user groups. One explanation for this finding might be that the user groups relied more heavily than the non-users upon the short-term visual cache component of visual memory which does not draw upon the central executive (Pearson et al. *1999*). This would imply sacrificing some processing of spatial sequencing information in comparison with non-users in all of the task conditions. As the demands on the central executive increased the performance of the non-users would then be relatively more vulnerable to impairment than that of the user groups, consequently producing the pattern of results shown in Table 3. While remaining conjecture, this explanation raises the possibility of a stable difference in the processing of visuospatial information existing between the MDMA users and non-users studied, which was present in all task conditions. However, this is clearly a matter requiring further research

before firm conclusions may be reached.

The present study has a number of limitations which should be noted. Greater detail of the use of other drugs could be gathered so that further analysis of the relationship of such usage to visuospatial working memory could be conducted. The group of former MDMA users was small (i.e. *n*=10), as participants matching the inclusion criterion of 6 months abstinence proved extremely difficult to recruit. The presence (or otherwise) of cognitive deficits in MDMA users on a long-term basis is clearly an important area for future research. This study also relied upon self-report data concerning drug use, so that short-term intoxication effects on the day of testing cannot be entirely ruled out. However, this reliance is common to other studies of MDMA users (Fox et al. *2002*; Morgan et al. *2002*). Whilst the precise constituents of black market drugs, such as the 'ecstasy' tablets used by our participants, will always be an area of concern in a study like this, it should be noted that the majority of such tablets examined by the Forensic Science Service in the United Kingdom in 2001 contained 60–90 mg of MDMA (*M*=74.1 mg, Forensic Science Service *2002*). Furthermore, Parrott (*2004*) reviewed studies of the purity of 'ecstasy' tablets in samples from a variety of sources (e.g. amnesty bins) in the United Kingdom and elsewhere, and concluded that United Kingdom samples from the late 1990s to the early 2000s (in common with other countries) were characterised by high levels of MDMA. It is reasonable to assume, therefore, that the black market 'ecstasy' tablets consumed by our participants did, for the most part, contain active doses of MDMA.

In conclusion, this study is part of a growing body of literature suggesting that users of MDMA are characterised by cognitive impairments which may be related to their use of the drug, and that these impairments may be long-term in nature. Further research into the long-term implications of MDMA use is recommended as a priority.

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