

Syllogistic Reasoning Performance in MDMA (Ecstasy) Users.

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Abstract.

Previous research has demonstrated working memory and executive deficits in recreational users of MDMA (3,4-methylenedioxymethamphetamine; “Ecstasy”). In turn, both of these constructs have been implicated in syllogistic reasoning performance. Twenty-two MDMA users (mean age 21.36) and 26 non-MDMA user controls (mean age 21.31) were tested on syllogisms of varying difficulty, and on measures of working memory and executive functioning. MDMA users were significantly impaired in aspects of syllogistic reasoning and the effect remained significant after controls for the use of other drugs. However, the MDMA-related variance was reduced to below statistical significance following control for group differences in working memory span. The results are consistent with the possibility that MDMA-related deficits in aspects of executive functioning result in impaired reasoning performance among MDMA users.

Syllogistic reasoning performance in normal populations has been shown to rely on working memory and executive resources (Fisk & Sharp, 2002; Gilinsky and Judd, 1994). The purpose of the present paper was to establish whether MDMA-related deficits in these aspects of cognitive functioning (Curran & Travill, 1997; Morgan, McFie, Fleetwood & Robinson, 2002) might give rise to syllogistic reasoning deficits. Since syllogistic reasoning is generally regarded as an indicator of the capacity for rational thought, MDMA-related deficits on this measure raise the possibility that extensive use of MDMA might be associated with impaired rational thinking.

A key construct in cognitive psychology is Baddeley's (1986) model of working memory. The model consists of phonological and visuo spatial components and an executive system which co-ordinates these and is responsible for managing goal directed behaviour and reconciling processing conflicts. The working memory system is believed to underpin a wide range of key cognitive processes, for example, learning to read (Hitch, Towse, & Hutton, 2001) the development of arithmetic competence (Hitch et al, 2001; Trbovich & LeFevre, 2003), knowledge and skill acquisition (Head, Raz, Gunning-Dixon, Williamson, & Acker, 2002) and thinking and reasoning (Stanovich & West, 2000). Previous and current MDMA users have been found to exhibit impairments in working memory functioning. For example, Wareing, Fisk, Murphy & Montgomery (2004) found that MDMA users were impaired on the computation span measure. Computation span is an established indicator of working memory functioning loading on both the phonological and executive components (Salthouse & Babcock, 1991). Wareing et al (2004) observed that MDMA users were impaired specifically on the executive component of the task. MDMA related deficits have also been found in other aspects of executive

functioning, for example, the subtracting serial sevens task (Curran & Travill, 1997) and the Tower of London task (Fox, McLean, Turner, Parrott, Rogers, & Sahakian, 2002).

An important area of cognitive functioning that has not been directly addressed with regard to MDMA users is reasoning. Of the broad range of intellectual abilities that has been investigated, reasoning is perhaps the most cognitively demanding. There is cause to believe that among the many illicit drugs commonly in use, MDMA in particular has the potential to disrupt reasoning processes. The drug is believed to have long term adverse effects on the serotonin system (Morgan, 2000). In turn, the serotonin system is believed to underpin the operation of working memory processes through its modulation of the dopaminergic systems that support prefrontal executive processes (Luciana, Collins, & Depue, 1998; Robbins 2000). Indeed in his review of the literature, Morgan (2000, page234) has noted that ‘it has been proposed that it [serotonin] may play an orchestrating role in cognition’. However, the possibility that MDMA users might be impaired in reasoning, and more specifically in syllogistic reasoning, has not yet been investigated.

Syllogistic reasoning requires a participant to draw valid inferences from a set of premises. For Example,

Given that:	Some A are B,
	and
	No B are C
It follows that:	Some A are not C.

Johnson-Laird (1983) maintains that reasoning involves constructing mental models of the premises and testing conclusions against these models. Constructing a single

model may solve some problems, others may require up to three models¹. The more complex the problem, the greater number of models required and the greater the load on working memory and executive resources. Syllogistic reasoning is also believed to utilise resources outside of working memory, for example relations between linguistic concepts such as ‘all’, ‘some’ and the logical operator ‘not’, as well as spatial representations of class inclusion relationships (see, for example, Ford, 1995).

Among the different measures of reasoning competence, syllogistic reasoning is perhaps one of the best known. It was central in the development of Johnson-Laird’s mental models theory (Evans, Handley, Harper & Johnson-Laird, 1999; Johnson-Laird, 1983). Within a developmental context, it has been used as a key indicator of reasoning competence in early childhood (Lourenco & Machado, 1996) and over the adult lifespan (Gilinski & Judd, 1994; Fisk & Sharp, 2002). Syllogisms have also featured prominently in the debate on human rationality (e.g., Stanovich & West, 2000). Given that MDMA use has been associated with impaired working memory and executive functioning and that these cognitive constructs are believed to underpin syllogistic reasoning performance (e.g., see Fisk & Sharp, 2002; Gilhooly, Logie and Wynn, 1999), it seems reasonable to expect MDMA users might be impaired on this measure of reasoning ability.

In evaluating the potential effects of MDMA, controls for the effects of other drugs, especially cannabis, are necessary. Cannabis has been found to adversely affect several aspects of executive functioning including the organisation and integration of information (Hall & Solowij, 1998), verbal fluency performance (Croft, Mackay, Mills, & Gruzelier, 2001; Klugman, Hardy, Baldeweg, & Gruzelié, 1999), and among heavy users, perseveration errors on the WCST (Pope & Yurgelun-Todd, 1996). While there is no direct evidence that cannabis affects syllogistic reasoning, since the

drug appears to impair certain executive processes, it is possible that reasoning might be affected as a consequence. The present study will therefore attempt to control for the effects of cannabis and other drugs.

To sum up, it is expected that MDMA users will perform worse compared to controls in a syllogistic reasoning task and that the MDMA related deficit will be most pronounced on the two and three-model syllogisms, as these load most heavily on working memory and executive resources. ANCOVA will be used to investigate the extent to which MDMA-related differences in syllogistic reasoning are related to group differences in working memory capacity and executive functioning. Working memory and executive functioning will be assessed through a computation span task and through random letter generation.

METHOD.

Participants.

Twenty-two MDMA users (11 males, 11 females) and 26 non-MDMA user controls (10 males, 16 females) between the ages of 18-25 were recruited. Participants were initially recruited through direct approach to Liverpool John Moores University undergraduate students, including psychology majors and psychology-biology joint students. Subsequently, word of mouth referral was used, with most participants being recruited by this means. Participants were requested to refrain from MDMA use for at least 7 days and ideally 10 days prior to testing (the mean period of abstinence was actually 4.61 weeks). Participants were also requested not to use any other illicit drugs for at least 24 hours and ideally for 7 days prior to testing². Participants were paid 15 UK pounds in store vouchers for their participation.

Materials.

Fluid intelligence was measured through Raven's progressive matrices (Raven, Raven & Court, 1998). Premorbid intelligence was assessed through the National Adult Reading Test (NART, Nelson 1982). A background questionnaire used by Montgomery, Fisk, and Newcombe (2004) assessed the use of MDMA and other drugs, as well as age, years of education, general health, and other lifestyle variables. In relation to other drugs, among other things, participants were asked to indicate their frequency of use and the last time that they had used each drug. Cigarettes smoked per day and units of alcohol consumed each week were also assessed. Participants were also questioned concerning their history of drug use. Using a procedure developed by Montgomery, et al (2004), these data were used to estimate total lifetime use for each drug.

Syllogistic reasoning. The syllogisms were presented in abstract form as in the example set out above. Participants attempted to generate solutions for four one-model syllogisms, four three-model syllogisms, and four syllogisms for which there was no valid conclusion (NVC). The syllogisms were the same as those used by Fisk and Sharp (2002). Scores were based on the number of correct solutions, or in the case of the NVC syllogisms, a response was deemed correct when the participant indicated that no valid conclusions were possible. According to Johnson-Laird (1983), NVC syllogisms require either two or three mental models in order to derive the correct solution. In the present study, two of the NVC syllogisms were two-model and two were three-model. Therefore, in terms of the number of models required, three-model and NVC syllogisms were the hardest, and one-model the easiest. The syllogisms used in the study were presented in random order. The test was administered following the procedure outlined by Fisk and Sharp (2002).

Working memory and executive functioning. The computation span measure and random letter generation were used to assess these aspects of cognitive functioning. Computation span has been used as an indicator of working memory functioning in the cognitive ageing literature (Fisk & Warr, 1996; Salthouse & Babcock, 1991) and it is similar to the operation span measure used by Miyake, Friedman, Emerson, Witzki, Howerter, & Wager (2000) in their investigation of executive processes. Participants were required to solve a number of arithmetic problems (e.g., $4+7 = ?$) by circling one of three multiple-choice answers as each problem was presented. They were also required to simultaneously remember the second digit of each presented problem. At the end of each set of problems the second digits had to be recalled in the order in which they were presented. The number of arithmetic problems that the participant had to solve, while at the same time remembering each second digit, gradually increased as the test proceeded. For each of the first three trials only a single problem was presented. For the next three trials, two problems were presented. Subsequently, the number of problems presented per trial increased by one every third trial. In order to proceed, the participant was required to be correct in at least two of the three trials at the current level. Computation span was defined as the maximum number of end digits recalled in serial order, with the added requirement that the corresponding arithmetic problems had been solved correctly. Since computation span is reliant on both phonological and executive processing resources, a simple digit span task (Fisk & Warr, 1996) was also administered so that it could be ascertained that any observed MDMA related deficits were not simply a result of lower level non executive impairments (i.e., the phonological loop).

Random generation is an established measure of executive functioning. For example it features prominently in both Baddeley's (1996) and Miyake et al's (2000)

accounts of executive processes and, using the dual task methodology, it has been studied directly in relation to syllogistic reasoning performance (Gilhooly et al, 1999). We used the procedure developed by Baddeley (1966). However, a computer display and concurrent auditory signal was used to pace responses. Participants were asked to speak aloud a letter every time the signal was presented. They were told to avoid repeating the same sequence of letters, to avoid producing alphabetical sequences, and to try to speak each letter with the same overall frequency. Individuals attempted to produce three sets of 100 letters; one set at a rate of one letter every 4 s, a second set at one letter every 2 s, and a third at one letter every 1 s. The order in which the sets were generated was randomised. The experimenter recorded the responses on an answer sheet. The test yields four scores, first, the number of alphabetically ordered pairs, second, a repeat sequences score, corresponding to the number of times that the same letter pair is repeated, third, a “redundancy” score, which measures the extent to which all 26 letters of the alphabet are produced equally often (0% being truly random), and fourth, the number of letters produced. In the first three cases, higher scores indicate poor performance; in the fourth the opposite is the case. The scores for each separate variable, at each of the three generation rates, were standardised. A single random generation score for each participant was produced by averaging the standardised scores, reversing the sign for the number of letters generated so that for the overall measure, a positive score was indicative of poor performance.

Sleep Quality. Research has shown that MDMA users exhibit altered sleep patterns, with less total sleep time and qualitative changes in the characteristics of Stage 2 sleep (Allen, McCann & Ricaurte, 1993). It has been suggested that apparent MDMA-related cognitive deficits might simply be due to the fact that MDMA users get less sleep (Cole, Sumnall & Grob, 2002). To assess this possibility, a screening

questionnaire and the Epworth Sleepiness Scale (Johns, 1991) were used to investigate any group differences in sleep quality and wakefulness. The Epworth scale measures subjective daytime sleepiness. It contains eight items, which a participant has to score on a scale of 0 = would never doze off in this situation, to 3 = high chance of dozing off in this situation. Summing the responses to all eight items produced an overall total score. The screening questionnaire contained a number of questions on sleep quality, as detailed in the notes to Table 1.

Procedure.

Informed consent was obtained. The tests were administered under controlled laboratory conditions. A computer, using MS-DOS was used for the digit span, computation span and random letter generation tests. Tasks were administered in the following order: Health/education questionnaire, MDMA background questionnaire and sleep questionnaires, random letter generation, digit span test, computation span test, syllogistic reasoning test, NART, and finally Ravens progressive matrices. The order of the random generation, computation span and syllogistic reasoning tests was rotated, to eliminate order effects. Overall, testing took between two and three hours at the end of which, the participant was debriefed and provided with drug education leaflets. The study was approved by the Ethics Committee of Liverpool John Moores University, and was administered in accordance with the ethical guidelines of the British Psychological Society.

Design.

A mixed design was used with MDMA user group (with two levels, user/non-user) as the between participants variable, and level of difficulty of the syllogism

(again with two levels, low and high) as the within participants variable. Level of difficulty was based on the number of models required to derive a solution. Thus one-model syllogisms were low in difficulty. Since the NVC and three-model syllogisms require a similar number of models to produce a solution, responses for these types were combined to form the high difficulty level. The dependent variable was the number of correct solutions for the low and high difficulty syllogisms (maximum score was eight in both cases). We also sought to determine whether the main effect of user group was qualified by a user-by-difficulty interaction. In common with established practice, analysis of covariance (ANCOVA) was used to statistically control for group differences in potentially confounding or moderating variables (see for example, Fisk & Sharp, 2002; Morgan, 1999; Verkes, Gijsman, Pieters, Schoemaker, Visser, Kuijpers, et al, 2001; Wareing, Murphy, & Fisk, 2004). Thus, where appropriate, indices of other drug use, sleep quality, and working memory measures were included as covariates.

RESULTS.

Background Variables.

Average age, years of education, fluid intelligence, premorbid intelligence, and other background variables for the two groups are set out in Table 1. Statistical tests (ANOVA, t-test, Mann Whitney U, and Chi squared) revealed that there were some significant group differences among the background variables. MDMA users performed worse than non-users on the computation span test, $F(1,45) = 15.92$, $p < .001$. With regard to wakefulness, most users considered themselves to be evening types, whereas nonusers made neutral responses or stated that they were morning types, Mann-Whitney $U = 181.50$, $p < .05$.

< Insert table 1 about here >

Inspection of Table 2 reveals that the use of “other” drugs was commonplace among MDMA users, while among non-MDMA users, drug use was mainly limited to alcohol, cannabis, and tobacco. There were large differences between MDMA users and non-MDMA users in the total number of cannabis “joints” smoked, the mean period of abstinence from cannabis, and the frequency of cannabis use. For total number of joints smoked and period of abstinence these differences were non-significant $t(20) = 0.92$, and $t(11.04) = -1.53$, respectively, $p > .05$ in both cases. In both cases standard deviations were large and Levene’s test was significant in relation to period of abstinence. Clearly, these non-significant results need to be treated with caution given the relatively small number of cannabis users among the non-MDMA group. The group difference was significant for frequency of cannabis use, $t(14.98) = 2.94$, $p < .05$.

< Insert table 2 about here >

Syllogistic Reasoning: Main Analysis.

Table 3 reveals that MDMA users performed worse than non-users both on the one-model and on the three-model/NVC syllogisms although in the latter case the group difference was less pronounced. Mixed ANOVA yielded a significant models by user interaction, $F(1,46) = 5.56$, $p < .05$, with an effect size of 10.8% (i.e., partial eta squared = .108). Subsequent analyses revealed that MDMA users performed significantly worse on the one-model syllogisms, $F(1,46) = 11.24$, $p < .01$, but there was little difference between the groups on the NVC/three-model problems, $F < 1$.

< Insert table 3 about here >

Covariate Analyses.

Working memory and executive functioning. It is possible that the observed MDMA related deficit in syllogistic reasoning might be mediated by working memory components. MDMA users performed significantly worse than nonusers on the computation span measure. ANCOVA with computation span as a covariate generated a significant result with respect to computation span, $F(1, 44)=7.23, p<.05$.

Consistent with this, the interaction effect between MDMA user group and models, on syllogistic reasoning, was reduced to below statistical significance after control for differences in computation span³, $F(1,44) = 2.41, p>.05$, and the effect size was reduced to 5.2%, approximately half its original magnitude. The main effect of user group was also reduced to below statistical significance⁴, $F<1$. By way of contrast, ANCOVA with random letter generation as a covariate generated a non-significant result with respect to random generation, $F < 1$. The interaction effect between group and models, on syllogistic reasoning, remained significant after control for random generation, $F(1,45) = 4.59, p<.05$, and at 9.3% the effect size was barely reduced at all. In both analyses the group by covariate interactions were non-significant, $F < 1$, indicating that homogeneity of regression was obtained.

Sleep Quality. As noted above, with regard to whether individuals viewed themselves as morning or evening types, relative to nonusers, MDMA users were more likely to see themselves as evening types. To establish whether this outcome had any effect on group differences in reasoning performance, each participant's ordinal response for the sleep type variable (ranging from 1 = definitely a morning type, to 5 = definitely an evening type) was entered as a covariate and the main analysis repeated. This produced a non-significant result with respect to the covariate, $F< 1$, and the groups by models interaction effect on syllogistic reasoning remained

significant, $F(1,45) = 4.52, p < .05$. Homogeneity of regression was obtained, $F < 1$ for the group by covariate interaction. Thus it appears that group differences in aspects of sleep quality were not responsible for the MDMA related impairments in syllogistic reasoning performance⁵.

Other Drugs. It was necessary to establish whether the prevalence of polydrug use, especially among the MDMA user group (see Table 2), contributed to the MDMA-related differences in reasoning performance. ANCOVA with frequency of cannabis use as a covariate⁶ reduced the interaction between group and models to below statistical significance, $F(1,45) = 2.15, p > .05$. The main effect of user group was also reduced to below statistical significance, $F(1,45) = 2.57, p > .05$. Homogeneity of regression was obtained, $F < 1$, for the group by covariate interaction. However, subsequent ANCOVA with the number of correct one-model syllogisms as the sole dependent variable, group between participants, and frequency of cannabis use as the covariate, left the main effect of group statistically significant, $F(1,45)=4.64, p < .05$, and homogeneity of regression was obtained, $F(1,44)=1.75, p > .05$, for the group by covariate interaction.

The possibility that prolonged cannabis use might produce a cumulative decrement in syllogistic reasoning performance was also evaluated. An estimate of lifetime cannabis use was included as a covariate⁷ and the main analysis was repeated. The interaction between groups and models was reduced to just below significance, $F(1,45) = 3.71, p = .061$. However, the main effect of user group remained significant, $F(1,45) = 3.77, p < .05$, one tailed. Homogeneity of regression was obtained, $F < 1$, for the group by covariate interaction. Again, subsequent ANCOVA with the number of correct one-model syllogisms as the sole dependent variable, group between participants, and lifetime cannabis use as the covariate, left the main effect of group

statistically significant, $F(1,45)=7.15$, $p<.05$, and homogeneity of regression was obtained, $F<1$, for the group by covariate interaction.

In view of the fact that some of the participants, both MDMA users and nonusers, had smoked cannabis during the week prior to testing, for all cannabis users, time since last use of cannabis was correlated with performance on the syllogisms. This yielded non significant correlation coefficients of .05 and .07 for the one-model and the three-model/NVC syllogisms respectively, $p>.05$, $n=29$, in both cases.

Thus on balance it appears that the MDMA-related deficits in syllogistic reasoning remain significant following statistical controls for various measures of cannabis use. Nonetheless the possibility that cannabis exerts an influence cannot be entirely excluded. The correlation coefficient between lifetime use of cannabis and performance on the one-model syllogisms was -0.36 , $p<.05$. This compares with a correlation of -0.40 , $p<.01$, between lifetime use of MDMA and performance on the one-model syllogisms, (for the three-model/NVC syllogisms neither of the equivalent correlations were statistically significant).

While 55% of MDMA users smoked cigarettes, only 23% of nonusers were smokers. Therefore it is possible that users might have been more susceptible to nicotine deprivation during testing. Furthermore, while both groups consumed alcohol regularly, MDMA users consumed almost twice as many units per week compared to nonusers. To evaluate the potentially confounding effects of these variables, the number of cigarettes consumed per day and the units of alcohol per week were entered as covariates. The interaction between groups and models was reduced to just below significance, $F(1,44) = 3.54$, $p=.067$. However, the main effect of user group

remained significant, $F(1,44) = 7.45$, $p < .01$, and homogeneity of regression was obtained, $F < 1$, for the two group by covariate interactions.

With regard to the use of other illicit drugs, Table 2 reveals that MDMA users had previously consumed amphetamine and mushrooms. In addition they were also currently consuming poppers and cocaine. It would have been desirable to statistically control for the effects of these other drugs; however, there were insufficient users of them among the non-MDMA user group to perform ANCOVA since it was not possible to properly test for homogeneity of regression. To try to distinguish the effects of the individual drugs, multiple regression analysis was conducted. Two separate regressions were run, the first with the number of correct responses on the one-model syllogisms as the dependent variable, the second with the number of correct responses on the three-model/NVC syllogisms as the dependent variable. For both regressions, independent variables were estimates of lifetime consumption of amphetamine, cannabis, cocaine, and MDMA⁸. For the one-model syllogisms the regression model accounted for a significant proportion of the variance, $R^2 = .243$, $F(4,43) = 3.45$, $p < .05$. However, the regression model failed to reach significance for the three-model/NVC syllogisms, $R^2 = .063$, $F < 1$. Examination of Table 4 reveals that for the one-model syllogisms total lifetime use of MDMA was the only significant predictor, uniquely accounting for around 7% of the variance. With the exception of total use of cannabis, the standardised beta coefficients were negative for all of the predictors, indicating that performance on the one-model syllogisms declines as lifetime consumption of each of the predictors increases.

< Insert table 4 about here >

In situations where ANCOVA cannot be used and as an alternative to regression analysis, a further method to control for the potentially confounding effects of these other drugs is to exclude all users of each drug in turn and reanalyse the data. Although this technique has its limitations, in that it ignores the likelihood that there are correlations between the use of these other drugs, nonetheless it does provide at least some degree of control for their use. Therefore the main analysis, with user group between participants and models within, was repeated excluding all those who had used a particular substance during the last three months. This was done with respect to amphetamine, cocaine, mushrooms, poppers, and tobacco.

In all but one case this reduced the group by models interaction to below statistical significance. Specifically, F values for the models by user group interaction were as follows: $F(1,43) = 3.46$, $p=.070$, excluding amphetamine users; $F < 1$, excluding cocaine users; $F(1,44) = 6.69$, $p<.05$, excluding 'mushroom' users; $F(1,35) = 1.75$, $p>.05$, excluding 'poppers' users; and $F < 1$ excluding tobacco users. However, in each of the analyses the main effect of MDMA user group remained statistically significant with MDMA users obtaining fewer correct responses compared to nonusers. F values were as follows: $F(1,43) = 4.39$, $p<.05$, excluding amphetamine users; $F(1,34) = 12.31$, $p<.01$, excluding cocaine users; $F(1,44) = 5.31$, $p<.05$, excluding 'mushroom' users; $F(1,35) = 10.29$, $p<.01$, excluding 'poppers' users; and $F(1,28) = 4.92$, $p<.05$, excluding tobacco users. For MDMA users and non MDMA users respectively, sample sizes were 19 and 26 excluding amphetamine users; 11 and 25 excluding cocaine users; 20 and 26 excluding 'mushroom' users; 12 and 25 excluding 'poppers' users; and 10 and 20 excluding tobacco users.

Thus by way of summary, in relation to the possible confounding effects of these other drugs, the main effect of MDMA user group remained significant when

the analyses were rerun excluding users of each of the other drugs in question. Furthermore, in the regression analyses, among the total use variables that were included as independent variables, only MDMA proved to be significant as a predictor of performance on the one-model syllogisms.

DISCUSSION.

As expected, the present results demonstrate an MDMA related deficit in syllogistic reasoning. Furthermore since the average reported period of abstinence was 4.61 weeks, the results observed are unlikely to be a short-term consequence of using the drug. Contrary to expectations, there was no group difference on the NVC and three-model syllogisms. MDMA users did, however, perform significantly worse than nonusers on the one-model syllogisms. The absence of group differences on the NVC and three-model syllogisms is difficult to reconcile with Johnson-Laird's (1983) account of mental models theory. It does however provide further support for Evans et al (1999), who maintain that individuals generally construct only a single mental model of the premises and fail to search for alternatives. From either perspective, for both one-model and more complex syllogisms, the premises need to be retained so that alternative possible conclusions can be accepted or rejected in the context of the initial mental model and the contents of working memory updated as necessary. The MDMA related deficit evident in the one model context appears to be consistent with some degree of impairment in this process. In the NVC/three model situation where according to Evans et al only a single model is constructed, this model does not itself constitute an exhaustive representation of the implications of the premises and for both users and nonusers, most inferences derived from it are therefore likely to be erroneous. Therefore, consistent with the findings reported here, group differences

would not be expected on the NVC/three model problems. Apart from the present findings other evidence has been obtained consistent with Evans et al's conceptualisation of reasoning processes. For example, Newstead and co-workers have demonstrated that many individuals do not proceed beyond the initial model of the premises relying solely on it when constructing their inference (Newstead, Handley, & Buck, 1999; Newstead, Thompson, & Handley, 2002). Similar findings have been also reported by Handley, Dennis, Evans, & Capon (2000).

It was possible that any group differences in syllogistic reasoning were due to reduced working memory and executive resources rather than a specific deficit in underlying reasoning competence. Computation span was significantly lower in MDMA users, and when included as a covariate this measure accounted for half of the MDMA-related variance in syllogistic reasoning. This suggests that the MDMA related deficit in syllogistic reasoning might be attributable to executive impairment rather than a consequence of some fundamental deficit in underlying reasoning competence. However, this is not to minimise the implications of the present findings. Even if it is the case that underlying reasoning competence remains intact in MDMA users, given that they lack the executive resources to make full use of this capacity, they are still likely to exhibit impairments in the capacity for rational thought.

It is worthy of note that while there were MDMA-related differences in computation span, no such trend was evident in the random letter generation scores and inclusion of the latter as a covariate did not attenuate the group differences in reasoning performance. In fact previous research has shown that performance on the two working memory executive measures is not invariably correlated (Lehto, 1996; Miyake et al, 2000) and it has been argued that each measure loads on a qualitatively different aspect of executive functioning (Fisk & Sharp 2004, Miyake et al, 2000).

Thus the present results suggest that MDMA-related deficits are most apparent in those aspects of executive functioning captured by the computation span measure and that these deficits produce knock-on effects on reasoning performance.

A number of background variables were considered in the present study including various measures of sleep and wakefulness. These appear to play no part in the group differences in syllogistic reasoning that were obtained. However, the measures that were used were largely self-report and it remains possible that more physiologically based measures might have produced a different outcome. Therefore the possibility that sleep impairment mediates some or all of the MDMA-related effects cannot be totally excluded.

An important aspect that was addressed in the present study was the potentially confounding effect of other drugs. The use of other drugs was much more common among the MDMA user group, and with a few exceptions, the use of other drugs among the non-MDMA group was limited to alcohol, tobacco and cannabis. Analyses of covariance with various measures of alcohol, tobacco and cannabis use as covariates were conducted, and in all cases, at least in relation to the one-model syllogisms, MDMA users remained significantly impaired. Furthermore, regression analysis revealed that measures of total use of cocaine and amphetamine were not significant predictors of performance on the one-model syllogisms, indeed total use of MDMA was the only significant predictor. While these results highlight the importance of MDMA in accounting for the results obtained, the possibility that other drugs might exert some impact cannot be totally excluded. For example, total cannabis use among the whole sample was significantly and negatively correlated with performance on the one-model syllogisms.

It remains unclear whether this potential cannabis related effect is mediated through executive or non-executive processes. Interestingly, in the normal population, Fisk and Sharp (2002) found that syllogistic reasoning performance was positively correlated with word fluency scores. In turn, it has been suggested that word fluency taps an important aspect of executive functioning: access to semantic memory (Fisk & Sharp, 2004). While there is little evidence to link MDMA with impaired word fluency performance, cannabis use has been found to produce such an effect (e.g., Croft et al, 2000; Klugman et al, 1999). Thus it is possible that cannabis impairs this aspect of executive functioning thereby producing a detrimental effect on syllogistic reasoning. However, it must be acknowledged that this possibility is speculative and requires further investigation.

A number of limitations were evident in the present study, for example, we were reliant on individuals being willing and able to provide an accurate account of their previous drug use. Furthermore, it was not possible to quantify the amounts of each psychoactive drug present within the tablets or joints consumed and additionally, because of limited resources, we were unable to use urine, saliva, or hair samples to confirm recent patterns of drug use. However, the drug use questionnaire was designed to check the internal consistency of the information provided. It is equally worthy of note that most of the published studies that have probed cognitive deficits among MDMA users have not resorted to urine, hair, or saliva testing (e.g., Fox et al, 2002; Morgan, 1999; Parrott & Lasky, 1998; Rodgers, 2000).

Aside from the issue of drug testing other limitations of the present study need to be acknowledged. For example, lifestyle differences and premorbid factors cannot be excluded as possible sources of group differences in studies of this nature. MDMA users may neglect their diet and physical health. Studies have reported that they suffer

from a range of sub-clinical conditions including depression, anxiety, paranoia, and phobias (Morgan et al, 2002). Depression and anxiety have been shown to impair cognitive functioning (Eysenck & Calvo, 1992; Murphy, Michael, Robbins, & Sahakian, 2003) and so it is possible that these aspects of psychological affect may have mediated some of the effects observed in the present study. This is clearly a possibility that needs to be addressed in future research. Furthermore, it has also been suggested that MDMA users are subject to a heightened state of impulsivity (Morgan, 1998). In the present study, this may have resulted in responses being produced before their logical necessity had been thoroughly probed. It is also important not to over generalise from the present findings. For example, given that word of mouth referral was used as the primary means of recruiting participants, our MDMA-user group may not be entirely representative of all MDMA users, especially those who consume the drug in settings that are unlike those frequented by those individuals constituting the present sample.

In conclusion, the results of the present study show that syllogistic reasoning is impaired among MDMA users. This impairment may be a consequence of an MDMA-related decline in aspects of working memory and executive functioning. Furthermore, while the impairment appears to be associated with MDMA use, it remains possible that other drugs including cannabis may also exert an influence either independently or in conjunction with MDMA.

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Table 1.

Performance of MDMA users (n=22) and Nonusers (n=26) on Background Variables.

	MDMA user		Non-User	
	Mean	S.D.	Mean	S.D.
Age	21.36	1.67	21.31	1.69
Education (years)	15.05	2.84	15.96	1.89
Raven's Total Score	47.43	6.53	48.28	5.52
NART	27.95	7.60	30.19	6.07
Digit span	6.52	1.21	6.88	1.21
Computation span	3.00	1.58	4.88	1.63***
Random generation	0.05	0.38	-0.09	0.28
Self report health (median)	4	-	4	-
Epworth Sleep Scale (total score)	5.33	2.67	6.50	2.53
Sleep hour per night	8.09	1.49	8.10	0.85
Sleep Refreshed (median)	2	-	2	-
Sleep Quality (median)	2	-	2	-
Sleep Morning/Evening Type (neutral/morning type, %)	23	-	46*	-
Sometimes miss out a night's sleep (%)	86	-	73	-

Questions and Response alternatives.

Sleep Refreshed: How refreshed do you feel in the morning?

Responses: 1= very alert, 2 = fairly alert, 3 = fairly tired, 4 = very tired.

Sleep Quality: How well do you normally sleep at nights?

Responses: 1 = very well, 2 = satisfactory, 3 = not very well, 4 = very badly.

Sleep Morning/Evening Type: We hear about people who feel better in the morning or who feel better in the evening. Which of these two types do you think you are? Responses, 1= definitely a morning type, 2= more morning than evening, 3= neither one nor the other, 4= more evening than morning, 5= definitely an evening type.

Statistical Tests.

Age, education, Raven's, digit span, computation span, random generation: t test.
Self report health, sleep refreshed, sleep quality, sleep morning/evening type: Mann-Whitney U. Sometimes miss out a nights sleep: chi-squared.

*** $p < .001$; * $p < .05$

Table 2

History of Drug Use

	MDMA user			Non-User			
	Mean	S.D.	n	Mean	S.D.	n	p
Lifetime Use: Number of MDMA Tablets consumed	303.30	374.04	22	-	-	-	-
Length of MDMA Use (weeks)	164.82	99.58	22	-	-	-	-
Weeks since MDMA last used	4.61	6.82	22	-	-	-	-
Frequency of MDMA use (times per week)	0.47	0.40	22	-	-	-	-
Cigarettes (number per day)	9.62	4.19	13	11.50	4.87	5	ns
Alcohol (units per week)	21.82	11.14	22	11.83	8.19	26	***
Other Drugs							
Frequency (current users only) times per week							
Cannabis	2.58	2.54	15	0.63	0.31	6	*
Cocaine	0.76	0.54	11	-	-	-	-
Lifetime Use:							
Amphetamine (g)	102.20	220.14	5	-	-	-	-
Cannabis (joints)	4700.44	7040.93	16	1986.00	1883.40	6	ns
Cocaine (g)	56.84	79.26	11	-	-	-	-
Weeks since last use							
Amphetamine	62.24	92.89	10	-	-	-	-

Cannabis	1.68	4.64	18	9.23	15.99	11	ns
Cocaine	6.75	15.53	16	2.00	-	1	-
Mushrooms	62.98	66.75	7	-	-	-	-
Poppers	15.91	18.17	19	52.00	-	1	-

Percentage of Participants
Using Other Drugs During
the 3 Months Prior to
Testing.

Alcohol	100	100
Amphetamine	14	0
Cannabis	86	46
Cocaine	50	4
Mushrooms	9	0
Poppers	46	4
Tobacco	55	23

*** $p < .001$; * $p < .05$; ns $p > .05$; via t test

Means and standard deviations relate only to those individuals taking the drug in question.

In some cases where individuals were only occasional users, they were unable to provide an accurate estimate of their lifetime use.

Table 3

Average number of correct responses for one-model syllogisms and NVC/three-model syllogisms for MDMA users (n=22) and non-users (n=26)

	Users		Non-users	
	Mean	S.D.	Mean	S.D.
One-model	3.45	2.13	5.27	1.61**
NVC/Three-model	1.45	1.99	1.81	1.58
Overall percentage correct	30.62		44.25	

** $p < .01$

Note: for the four one-model problems (for which there were two valid conclusions per syllogism), and the eight three-model/NVC syllogisms (for which there was one valid conclusion per syllogism), the maximum possible score was eight.

Table 4

Results from Regression Analysis with Number of Correct Syllogism Responses as Dependent Variables and Measures of Lifetime Use of Other Drugs as Independent Variables.

Independent variable	Standardised beta weight	t value	Squared semi-partial correlation coefficient
Total lifetime use:	<u>Correct One-model Syllogisms</u>		
Amphetamine	-.260	-0.65	.007
Cannabis	.197	0.66	.008
Cocaine	-.175	-0.55	.005
MDMA	-.408	-2.03*	.072
Total lifetime use:	<u>Correct Three-model/NVC Syllogisms</u>		
Amphetamine	-.639	-1.43	.045
Cannabis	.179	0.54	.006
Cocaine	.445	1.25	.034
MDMA	-.246	-1.10	.026

* $p < .05$

¹ While a full description of the distinction between one, two, and three model syllogisms is beyond the scope of the present paper, such a description can be found in Fisk and Sharp (2002, pp 1274-5) and Johnson-Laird (1983, pp. 98-100).

² For those persons using other illicit drugs, the mean period of abstinence in weeks was 62.24 for amphetamine, 4.55 for cannabis, 6.47 for cocaine, 62.98 for ‘magic mushrooms’, and 17.71 for ‘poppers’.

³ Control for digit span produced no substantial degree of attenuation. The interaction between group and models remained significant, $F(1,44) = 6.03$, $p < .05$, with the effect size 12.0%.

⁴ Prior to the inclusion of computation span as a covariate, the main effect of user group yielded $F(1,46) = 6.41$, $p < .05$.

⁵ It is possible that Ecstasy related differences in the morning/evening type ratings may have played some role in producing the computation span group differences thereby indirectly accounting for some of the syllogistic reasoning deficits. However, ANCOVA with computation span as the dependent variable, Ecstasy user group as the independent variable, and the sleep measure as a covariate, left the group difference in computation span and the corresponding effect size intact, $F(1,44) = 17.05$, $p < .001$. Thus it appears that the sleep measure plays no role, either direct or indirect, in accounting for the syllogistic reasoning deficit.

⁶ A value of zero was entered for those persons who had never consumed cannabis

⁷ A value of zero was entered for those persons who had never consumed cannabis.

⁸ It is difficult to meaningfully quantify lifetime consumption of poppers so this substance was not included in the regression analyses.