A comparative study of the effects of methamphetamine on memory in existing and recovering addicts from a South African population

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Memory is a complex of systems by which an organism registers, stores and retrieves exposure to an event or experience. Literature purports that methamphetamine users and dependents have been found to exhibits signs of memory impairment. The aim of the research was to establish the possible existence of significant differences in memory in current methamphetamine users, recovering methamphetamine users, and a matched drug naïve control group. Cognitive functioning was assessed via a neurocognitive test battery that examined the memory of 14 current methamphetamine users, 17 recovering methamphetamine addicts, and 18 drug naïve control participants who were matched according to the demographic variables of age, gender and educational status. The results indicated that recovering methamphetamine users experienced the greatest impairment in memory in comparison to both the control group and current users of methamphetamine. The current users of methamphetamine also experienced some impairment in memory functioning in visual acquisition and retention. The poor performance of the recovering addicts is explained by the juxtaposition of the stimulating and supplemental effect of methamphetamine as experienced by the current users versus the neurotransmitter depletion and structural changes in the brain experienced by the recovering addicts. The control group showed a superior performance since they did not suffer from the neurotoxic effects of methamphetamine.

Geheue is 'n komplekse sisteem wat 'n individu in staat stel om blootstelling aan 'n voorval of ervarings te registreer, stoor, behou en herroep. Leer- en geheueprobleme is van die mees algemene simptome van neurosielkundige uitvalle in neurologiese en psigiatriese pasiënte. Die literatuur dui aan dat metamfetamienafhanklike verbruikers tipies geheuedisfunksie ervaar. Die doel van die navorsing was om die moontlike voorkoms van verskille in geheuefunksie in huidige gebruikers van metamfetamien, rehabiliterende gebruikers, sowel as 'n kontrolegroep van dwelmmiddel-naïewe demografies-passende individue te bepaal. Uitvoerende funksie is gemeet met 'n neurokognitiewe toetsbattery wat die geheuefunksies van 14 huidige gebruikers van metamfetamien, 17 rehabiliterende metamfetamienverslaafde individue en 18 dwelmmiddel-naïewe deelnemers, gepas in terme van ouderdom, geslag en opvoedkundige status, bepaal het. Die resultate dui aan dat dat die rehabiliterende metamfetamiengebruikers die grootste geheueuitvalle getoon het in vergelyking met sowel die huidige gebruikers as die kontrolegroep. Die huidige metamfetamiengebruikers het ook matige geheueuitvalle getoon, spesifiek in visuele leer en retensie. Dit is moontlik dat die geheueuitvalle wat deur metamfetamiengebruikers ervaar word, verband hou met strukturele en funksionele verandering in die breingebiede wat met geheue geassosieer word, as gevolg van metamfetamienvergiftiging. Die swak prestasie van die rehabiliterende metamfetamienverslaafde persone in vergelyking met die huidige gebruikers word verduidelik in terme van die naasmekaarstelling van die stimulerende en aanvullende effek van metamfetamien soos ervaar deur die huidige gebruikers versus die neurotransmitteruitputting en strukturele breinveranderinge in die rehabiliterende individue. Die kontrolegroep het 'n beter resultaat getoon omdat hulle geen neurotoksiese effekte van metamfetamien gehad het nie.

Introduction

Methamphetamine is a highly addictive psycho-stimulant (Barr *et al*. 2006:301) that has become increasingly abused over the past several years for its euphoric effects (Hart *et al*. 2001:75). Twenty-nine million people consumed amphetamine-type stimulants in the late 1990s, a larger number than that of people using cocaine and opiates combined (World Health Organisation 2001:7).

Problem Statement

The need for scientific investigations regarding the effects of methamphetamine use is highlighted by the express worldwide and local resurgence of methamphetamine prevalence and abuse (Barr *et al.* 2006:301; Cape Town Drug Counselling Centre [CTDCC] 2005; Volkow *et al*. 2001a: 377).

South Africa has a dearth of information on the effects of methamphetamine on memory in its own population despite the prevalence of use locally (Plüddemann, Myers & Parry 2008:964). The focus of South African investigations into the methamphetamine epidemic often revolve around the social and economic correlates of this drug use, as well as its links to mental health problems and violence (Kapp 2008:193–194; Simbayi *et al.* 2006:291–300).

Limited studies exist that evaluate the effects of methamphetamine on current users, but virtually no research exists on simultaneous comparative studies of the effects of methamphetamine use in current and recovering users in comparison to each and a matched control group.

Additionally, of the studies that focus their research on the deleterious neurological and neurocognitive effects of methamphetamine, many are centred on these effects in early stage recovering or abstinent methamphetamine addicts (Ernst *et al*. 2000:1344–1349; Gonzalez, Bechara & Martin 2007:155–159; Johanson *et al*. 2006:327–338; Kalechstein, Newton & Green 2003:15–29; Salo *et al*. 2005:310–313; Sekine *et al*. 2001:1206–1214; Sung *et al*. 2007:28–35; Volkow *et al*. 2001a:377–382, 2001c:2015–2021). There are few studies that focus on the neurological and neurocognitive effects of methamphetamine in current users (McKetin & Mattick 1998:181–184; Simon *et al*. 2000:222–231). There are also no known studies that compare the cognitive functioning of recovering methamphetamine addicts and current users simultaneously, particularly in South Africa.

Background

Methamphetamine is known locally as 'crystal meth' or 'tik'. Users often feel dramatic increases in energy, alertness, sexual arousal, appetite and pleasure, increased self-confidence and grandiosity, an overall sense of well-being, and reduced appetite (Abadinsky 1997:120; Levinthal 2005:101; Nordahl, Salo & Leamon 2003:318; Yudko, Hall & McPherson 2003:55). Chronic doses may result in negative symptoms such as tremors, hyperflexia (muscle spasms), malnutrition, bruxism (teeth grinding), athetosis (strange muscle movements), agitation, restlessness, rage, insomnia, anxiety, hallucinations of formication (the sensation of insects crawling under the skin), and paranoia with the potential of severe amphetamine-induced psychosis (Anglin *et al.* 2000:139; Barr *et al*. 2006:302; Levinthal 2005:101; Yudko *et al*. 2003:55). Users may suffer from increased blood pressure, body temperature (hyperthermia), breathing rate as well as cardiac arrhythmia, stroke and potential cerebral convulsions and coma (Barr *et al.* 2006:303).

Studies of methamphetamine users have found evidence to suggest that the effects of methamphetamine use extend well beyond the interval of active use. International pre-clinical and clinical studies have found that methamphetamine abuse has been associated with residual negative effects noted in long-term neural damage in humans including a number of chemical, metabolic, neuronal and or physiological alterations (Sekine *et al*. 2001:1212; Tong *et al*. 2003:899; Volkow *et al*. 2001a:381; Volkow *et al*. 2001b:387). Observations of methamphetamine users have also led researchers to conclude that the observed deficits users exhibit, in areas such as abstract reasoning, planning, memory, attention, executive functioning and behavioural flexibility, may be as a direct result of methamphetamine's neurotoxicity (Barr *et al*. 2003:301; Nordahl *et al*. 2003:317, 322; Yücel, Lubman, Solowij & Brewer 2007:961).

Locally, methamphetamine has become a serious public health concern in the Western Cape. A 41.5% increase in methamphetamine as a primary drug of abuse has been noted from 2002 to 2006 in Cape Town (Plüddemann, Myers & Parry 2008:964). The startling increase of methamphetamine use in South Africa is further exacerbated by the fact that 80% of methamphetamine users in the Western Cape are under 21 years of age, according to the South African National Council on Alcoholism and Drug Dependence (SANCA) (Morris & Parry 2006:471). These figures indicate an express need for continued scientific investigations into the effects of methamphetamine.

Objectives

The core research objectives explored in this study are explained as follows:

- To address the scarcity of literature and quantitative research on methamphetamine and its role in South Africa – particularly in a neuropsychological context – while providing a template upon which further research can build.
- To establish the existence of potential cognitive impairment in the area of memory in a group of 14 addicts currently using methamphetamine compared to a group of 17 abstinent recovering methamphetamine addicts and a matched control group of 18 participants.

Significance of the study

Little to no information exists on the physiological and psychological effects of methamphetamine on cognition, particularly on the actual neuropsychological prognosis of local methamphetamine users both current and recovering. As such, this study, as one of a limited number of studies that comparatively studies both current and recovering methamphetamine users simultaneously, will contribute to the existing international literature base surrounding methamphetamine and its neuropsychological effects.

In doing so, this research will also aid in addressing the dearth in research on methamphetamine and its effects on

the South African population. This is particularly important in South Africa where methamphetamine abuse has become widespread. Additionally, the comparative nature of this study may also aid in determining why methamphetamine treatment programmes are plagued by high relapse and low retention rates (Copeland & Sorenson 2001:91). Moreover, this information may further assist in the determination and construction of more effective rehabilitation and treatment programmes, with the possibility of contributing to the development of a promising prevention programme.

Research method and design

Design

The research utilised an ex post facto quantitative and comparative study design. An ex post facto design was deemed most appropriate for this study which studied the effects of an illegal substance that is dangerous and harmful, precluding the use of an experimental design. Therefore, only those people who are already using the drug at their own discretion, their own usage method and their own quantity were approached. It is comparative and quantitative as the research wishes to compare three different groups with each other in order to ascertain where possible quantifiable differences might occur. The present research was also conducted in a positivistic research paradigm in that the object of the study is independent of the researcher.

Sampling

Inclusion criteria for the research were described as follows: 1) all participants were required to be fluent in English; 2) over 18 years of age and under 40 years of age; 3) have a Grade 12 matriculation certificate or equivalent; 4) be free from psychosis upon testing; 5) have no diagnosed acute Axis 1 mental disorder diagnosis (excluding drug-induced depression), or aneurysm, head injury with a loss of consciousness, a history of temporal lobe epilepsy, HIV+ status, multiple sclerosis, attention deficit disorder with or without hyperactivity, a learning disability, or any other neurological or medical condition known to affect cognitive status. Recovering addicts and the control sample were required to be free from alcohol and sedatives at least 24 hours before testing. All potential participants not meeting the criteria were not excluded.

A total of 14 current methamphetamine users (9 male users, 5 female users) were sampled all of whom had a minimum of one year regular methamphetamine use, and were determined to be either substance dependent or abusers according to the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR) (American Psychiatric Association [APA] 2000:197, 199). The currently using participants were obtained via 'word-of-mouth' from recovering methamphetamine users and acquaintances from the greater Johannesburg area in Gauteng as this is where the current users resided.

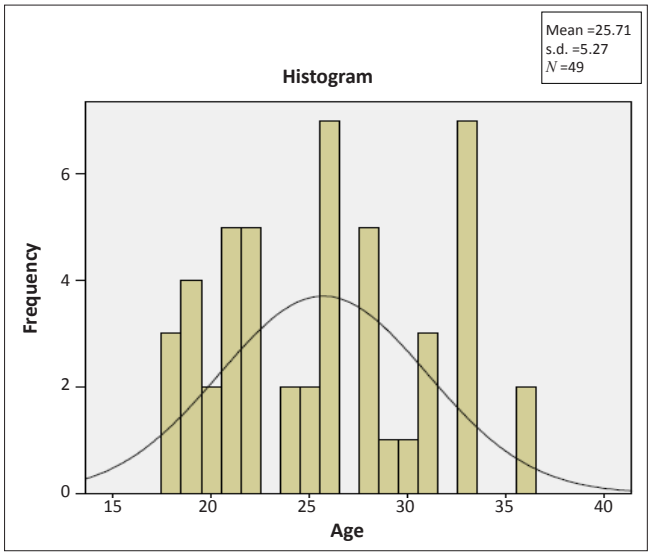
Seventeen recovering, treatment-seeking methamphetamine users (8 male users, 9 female users) were recruited from rehabilitation and treatment centres in Gauteng and the Western and Eastern Cape on recommendations from treatment professionals currently working within the treatment centres. These participants were required to have used methamphetamine regularly for a minimum of one year prior to seeking treatment, with a DSM-IV-TR (APA 2000:197, 199) diagnosis of substance abuse or dependence, and were required to be sober from all drugs and alcohol for a minimum of one month prior to this research's assessment. The sobriety of this group was ensured through urine screening as part of their inpatient status in the treatment facilities. Participants who were in outpatient programmes were asked to confirm their sobriety verbally and these assurances were assumed correct as they were still currently engaged in substance abuse treatment and rehabilitation.

The control group consisted of 18 participants (9 male users, 9 female users) who were found subsequent to the assessment of the two experimental groups through recommendations from peers according to the matching criteria and were required to be completely drug naïve. The control group was matched to the experimental groups according to age, gender and educational status.

No identifying information was required from the participants.

Neuropsychological Battery

Memory was assessed using the following neuropsychological tests: the Map Memory test, the Picture-Number test, and the



s.d., Standard Deviation

FIGURE 1: Histogram of Age Distribution for 2 Experimental Groups and 1 Control Group Combined.

TABLE 1: Gender Distribution of Participant Samples.

Group	*n*	Gender	
		Male	Female
Group 1 Current Users	14	9	5
Group 2 Recovering Addicts	17	8	9
Group 3 Control Group	18	9	9
Total	49	26	23

n, number of participants.

Auditory Number Span test from the Kit of Factor-Referenced Cognitive Tests (KFRCT) (Ekstrom *et al*. 1987:94, 102, 110).

The tests in the Kit of Factor-Reference Cognitive Tests (KFRCT) were developed in 1987 for the Educational Testing Service in Princeton, New Jersey and are based on factors identified by great names in psychology and psychometric testing such as Raymond Cattel, John Carroll, Thurstone, and J.P. Guilford (Ekstrom *et al*. 1987). The tests were designed for research purposes only, by the Office of Naval Research in the United States of America.

It is important to note that the reliability and validity of the measuring instruments in any study impact the generalisation capacity and appropriateness of the results obtained during the course of the research. The KFRCT (Ekstrom *et al*. 1987) consists of highly regarded researchers' tests and do not reflect reliability and validity coefficients in the testing manual. The current research therefore calculated the reliabilities of the following tests using the Cronbach's Alpha Test of Reliability. The psychometric properties of the tests are listed below.

The Map Memory Test

The Map Memory test is a two-part test of visual recall or recognition (Ekstrom *et al*. 1987:113). Each part requires a participant to 'study' a test sheet of 12 different maps for a period of four minutes. The participant is then presented with a testing page, which presents 12 maps of which some are the same and some are new. The participant is required to indicate whether they have (Y) or have not (N) seen the map on the previous study page. The scores from the two parts of the test are allocated, based on the number of correct identifications of previously seen and unseen maps and are added together to yield a single overall score.

The reliability for this test was determined during the course of the research using the Cronbach's Alpha Test of Reliability. This test produced internal consistency coefficients of also states that visual recognition 0.795 overall, which falls into the same bracket as other visual recognition tests. Lezak (1995) tests, such as The Map Memory Test from the KFRCT (Ekstrom *et al*. 1987:113), have reliability coefficients ranging from 0.7–0.8.

This test is similar to subtests from the Weschler Memory Scale, which has proven validity. Most of the participants in this study exhibited observational difficulty with visual memory and this test purports to assess visual recall and recognition, and as such the participants performed poorly on this test, ensuring the face validity of this test.

The Picture-Number Test

The Picture-Number Test is a visual learning (acquisition) and memory (retention) test in two parts (Ekstrom *et al*. 1987:94). In each part, the participant is presented with a page of 21 pictures of common items, which are paired with a two-digit number. The participants are given four minutes to 'study' this page after which they are instructed to turn to the 'test' sheet, which presents only the pictures in a different order than the study sheet. The participants are then required to fill in the corresponding number to match the picture in the three-minute time limit. Scores on this test are derived from the number of correct picture-number combinations that have been remembered and the two parts are added together to yield a single score.

This test showed internal consistency coefficients of 0.921 overall, with reliability coefficients of 0.887 for part one and 0.843 for part two. The test is similar to other paired-associate visual acquisition and learning tests as found in the Wechsler Memory Scale, which has proven validity, and thus the validity of this test is assumed.

The Auditory Number Span Test is a 'conventional digit span forwards test, which assesses storage and retrieval in short-term memory' (Ekstrom *et al*. 1987:101). Digit Span tests assess the limits of the participant's capacity for encoding and briefly retaining a series of numbers. This test has one condition of 24 digit series, yielding a single score, which determines the participant's ability to recall a number of distinct elements for instant reproduction (Ekstrom *et al*. 1987:102). The examiner reads out a digit series of varying lengths at the speed of one digit per second and, once the series has been read, the participant is allowed to write down what they can remember of the series.

This test produced internal consistency coefficients of 0.819 overall, which are high reliability coefficients. The Auditory Number Span Test is a conventional digit-span test that assesses immediate verbal retention by demonstrating an individual's ability to recall a number of distinct elements for immediate reproduction (Ekstrom *et al*. 1987:102). This digit-span test is similar to the one utilised in the Wechsler Memory Scale, which has good reported construct validity as a measure of verbal learning and memory (Larrabee, Kane & Schuck 1983:159).

Data collection method

The biographical questionnaire and neurocognitive test battery were administered in one hour to the participants in quiet surroundings that were both private and free from distraction. The biographical questionnaire served as both a screening process for inclusion and exclusion criteria, as well as a diagnostic tool to determine a DSM-IV diagnosis of substance abuse or dependence currently or previously.

This study was conducted across three provinces: Gauteng, the Eastern Cape and the Western Cape. Current methamphetamine users were interviewed and assessed in the privacy of their, or their friend's, home. Recovering methamphetamine addicts were interviewed and assessed at local rehabilitation centres (if inpatients), or public locations such as their homes or community centres (if outpatients). The control group was assessed and interviewed wherever was most favourable for them.

TABLE 2: Comparisons of Group 1 (Current Users) and Group 2 (Recovering Addicts) regarding their scores on the Memory Tests analysed by the Mann-Whitney Non-Parametric test of Variance.

Test	Group	*n*	Mean Rank	Sum of Ranks	Mean	s.d.	Asymp. Sig. (2 Tailed)
Map Memory	1. Current Users	14	21.21	297.00	18.714	3.688	.004*
	2. Recovering Addicts	17	11.71	199.00	14.000	4.373	-
	Total:	31	-	-	-	-	-
Picture- Number Test	1. Current Users	14	17.57	246.00	14.929	9.376	.380
	2. Recovering Addicts	17	14.71	250.00	12.294	7.465	-
	Total:	31	-	-	-	-	-
Auditory Number Span Test	1. Current Users	14	20.25	283.50	14.000	2.689	.018
	2. Recovering Addicts	17	12.50	212.50	10.824	3.779	-
	Total:	31	-	-	-	-	-

(Bonferroni Correction: threshold value adjusted to $p = .0167$)
s.d.,Standard deviation; *n*, number of participants.
*, indicates $p < 0.0167$

TABLE 3: Comparisons of Group 1 (Current Users) and Group 3 (Control Group) regarding the neurocognitive measures of Memory analysed using the Mann-Whitney Non-Parametric test of Variance.

Test	Group	*n*	Mean Rank	Sum of Ranks	Mean	s.d.	Asymp. Sig. (2 Tailed)
Map Memory	1. Current Users	14	15.39	215.50	18.714	3.688	.553
	3. Control Group	18	17.36	312.50	19.556	3.240	-
	Total:	32	-	-	17.388	4.485	-
Picture Number Memory	1. Current Users	14	11.57	162.00	14.929	9.376	.009*
	3. Control Group	18	20.33	366.00	23.444	8.082	-
	Total:	32	-	-	17.143	9.496	-
Auditory Number Span Test	1. Current Users	14	17.39	243.50	14.000	2.689	.633
	3. Control Group	18	15.81	284.50	13.944	3.472	-
	Total:	32	-	-	12.878	3.644	-

(Bonferroni Correction: Threshold Value Adjusted To $p = .0167$)
s.d.,Standard deviation; *n*, number of participants.
*, indicates $p < 0.0167$

TABLE 4: Comparisons of Group 2 (Recovering Addicts) and Group 3 (Control Group) regarding their scores on the neurocognitive measures of Memory analysed using the Mann-Whitney Non-Parametric test of Variance.

Test	Group	*n*	Mean Rank	Mean	s.d.	Asymp. Sig. (2 Tailed)
Map Memory Test	2. Recovering Addicts	17	11.82	14.000	4.373	.001*
	3. Control Group	18	23.83	19.556	3.240	-
	Total:	35	-	-	-	-
		-	-	-	-	-
Picture Number Test	2. Recovering Addicts	17	11.85	12.294	7.465	.001*
	3. Control Group	18	23.81	23.444	8.082	-
	Total:	35	-	-	-	-
Auditory Number Span	2. Recovering Addicts	17	13.88	10.824	3.779	.020
	3. Control Group	18	21.89	13.944	3.472	-
	Total:	35	-	-	-	-

(Bonferroni Correction: threshold value adjusted to $p = .0167$)
s.d.,Standard deviation; *n*, number of participants.
*, indicates $p < 0.0167$

Data analysis

Demographic information was used entirely for the purposes of inclusion and exclusion in the study and not analysed. Raw scores obtained from the neuropsychological test battery were statistically analysed using non-parametric tests of variance due to a non-assumption of normality resulting from small sample sizes in the present research.

Raw scores were obtained from the paper and pencil tests administered and these scores were initially subjected to multivariate data analysis using the non-parametric Kruskal-Wallis test in which a significance level of $p = .05$ was applied. If the Kruskal-Wallis Test indicated significant results, further statistical analysis was utilised to determine which particular measures were most sensitive to methamphetamine dependence amongst the three groups. This analysis was performed using the non-parametric Mann-Whitney *U*-test with a Bonferroni correction adjusting the *P* - value from $p = .05$ to $p = .0167$ for all the results. This was done to safeguard against multiple tests of statistical significance on the same data falsely giving the appearance of significance.

Ethical considerations

The research was conducted in accordance with the approved research protocol of the University of Johannesburg. Informed consent was obtained from participants before they took part in the testing, and participation was voluntary and fully confidential. Participants were also advised of the purpose, expected duration and procedures involved in the research, and their right to withdraw from the research at any time, in accordance with the Code of Research Ethics of the Professional Board for Psychology and the Human Sciences Research Council.

Participants were offered debriefing following the study, and the opportunity to obtain the results of the research on completion of the study will be provided. This study is non-intrusive, non-deceptive and does not endanger the participants physically or emotionally. In order to ensure that any incentives would not interfere with the treatment and development of the participants, cash incentives were excluded.

Results

All three neuropsychological tests of Memory displayed significance on the Kruskal-Wallis non-parametric test of variance and as such were further analysed using the Mann-Whitney *U*-test and the results are displayed below.

Table 2 results illustrate that the only statistically significant difference in the population mean ranks lies in the Map Memory Test of the Kit of Factor-Referenced Cognitive Tests (KFRCT) (p =.004) (Average Group 1 = 18.714 versus Group 2 = 14.000)). Group 1, the current users of methamphetamine, therefore significantly outperforms Group 2, the recovering methamphetamine addicts, on the visual recall and recognition aspects of the Map Memory test from the KFRCT.

Table 3 illustrates that Group 3 (Control Group) performed better than Group 1 (Current Users) in only one test of memory – visual acquisition and retention Picture Number Test of the KFRCT (.009) (Average Group 1 = 14.929 versus Group 3 = 23.444).

Table 4 illustrates that Group 3 (Control Group) significantly outperformed Group 2 (Recovering Addicts) on the visual acquisition and retention test of Map Memory [(p =.001) (Average Group 2 = 14.000 versus Group 3 =19.556)] and the recall and recognition Picture-Number Test [(p =.001) (Average Group 2 =12.294 versus Group 3 = 23.444)] from the KFRCT.

It is noteworthy that no groups displayed any significant differences on the Auditory Number Span test from the KFRCT.

Discussion

The neurocognitive subtests that assessed memory and displayed significant results in this research are the map memory and picture-number association. *Map Memory* assesses visual recall and recognition (Ekstrom *et al*. 1987). The *Picture-Number Association test* assesses visual learning (acquisition) and memory (retention). No significant results were found on the short-term auditory memory storage and retrieval functions assessed by the *Auditory Number Span test* (Ekstrom *et al*. 1987).

The overall current findings of this research therefore indicate that those individuals currently using methamphetamine and the control group outperformed the abstinent recovering methamphetamine users in the short-term visual-recognition and recall assessment of memory. The drug naïve control subjects also performed significantly better than both the current and recovering methamphetamine users on tests of visual learning (acquisition) and retention (memory). Based on these results the research posits that the efficacy of the control group's storage and retrieval of information from intermediate visual memory can be considered significantly better than both the current and recovering users of methamphetamine.

Corroboration of the findings of this research, that recovering methamphetamine addicts are impaired in short-term visual recognition and recall, and visual acquisition and retention is found in Moon *et al*. (2007:6) who found selective damage on visual memory in abstinent methamphetamine users. Kalechstein *et al*. (2003:217) also found that the abstinent methamphetamine users performed poorly relative to the control group on non-verbal measures of memory and learning, although not significantly so.

This research posits that the memory deficits experienced by both the current and recovering users of methamphetamine are due to their methamphetamine exposure and its resultant deleterious effects in user's brain morphology and chemistry.

Structural and functional changes in the brain areas associated with memory due to methamphetamine neurotoxicity are believed to underlie the memory deficits experienced by methamphetamine users. The loss of cognitive functionality in these areas of memory is mirrored in literature and is believed to be attributed, in part, to the considerable loss of neurotransmitter functionality in the brain. Projections from the substantia nigra to the basal ganglia are part of the dopaminergic pathway, and dopamine appears to be essential to the functioning of the basal ganglia and therefore may have an indirect role in memory formation (Kolb & Whishaw 2003:468, 480). Therefore a loss of dopamine production and stimulation, which occurs due to methamphetamine cessation, may result in deleterious effects in memory formation and, according to the results of this study's, visual and visual associative short-term recognition and recall. The current users of methamphetamine, however, are still experiencing the juxtaposition of the stimulating and supplemental effect of methamphetamine. These users are therefore seen to be not as severely affected in terms of the cognitive function of memory whilst they are still using the drug as it promotes dopamine production and stimulation, which helps stave off the negative cognitive effects of the drug. However, prolonged chronic use of methamphetamine leads to greater neurotoxicity and once sober from the drug these users are likely to experience greater impairments than those who stopped using methamphetamine earlier.

The current users of methamphetamine, however, were significantly outperformed in the short-term explicit associative visual memory test, the Picture-Number Test, by the control subjects. As this test assesses associative memory and the storage and efficacy of retrieval of information from intermediate visual memory (Ekstrom *et al*. 1987:93) it can be said that the current users of methamphetamine suffer impairment in these areas of memory. This impairment, as noted in comparison to a drug-naïve population, can therefore probably be considered as a direct result of the current use of methamphetamine in this experimental population.

Literature supports this assertion as this type of impairment has been seen in another study with methamphetamine users in which the cognitive deficit was apparent in the more

difficult memory tasks such as recall tasks – that rely heavily on retrieval information – than in recognition tasks (Simon *et al*. 2000:229). The study by Simon *et al*. (2000:222) is one of few that deals with current users of methamphetamine in comparison to non-drug using control subjects. The authors found a pattern of memory functioning consistent with a mild generalised retrieval deficit often found in older adults suggesting that methamphetamine has a similar degenerative effect on the brain as aging does. The research conducted by Simon *et al*. (2000:227) also supports the overall findings of this study as both the current and recovering methamphetamine users experienced significant difficulty in comparison to the control subjects on the more difficult memory task of associative visual memory.

Contradictory literature by Kalechstein *et al*. (2003:217) exists to refute the findings of the current study. They found that the methamphetamine users performed significantly poorer than the control group on measures of verbal learning and memory. However, the authors concede that their participants may have still been experiencing withdrawal symptoms, which may have impaired the recovering methamphetamine user's auditory memory, and thus confounded the study results.

McKetin and Mattick's (1998:181) research both supports and refutes the findings of the present research. They found that high dependence illicit amphetamine users were impaired on measures of verbal memory in comparison to the control subjects, whilst the low dependence group displayed no impairment. The implications of these findings are that memory impairment in methamphetamine users is related to the reported severity of drug use. The current research made no provision for controlling the amount of methamphetamine use and could not label its users as high or low dependence on the drug and therefore cannot claim to compare its results fairly against those of McKetin and Mattick (1998:181).

It has been discussed that neither the current methamphetamine users – recovering methamphetamine users – nor the control group had significant deficits in short-term auditory memory in comparison to each other. Therefore the storage and retrieval of information in short-term auditory memory is not significantly affected by methamphetamine use. The lack of differences in short-term auditory memory storage and retrieval between the current users of methamphetamine, recovering users and the control subjects has been both supported by Moon *et al*. (2007). The authors found that methamphetamine causes selective damage on visual, but not verbal memory in methamphetamine users because visual memory tasks are more sensitive to executive dysfunction (Moon *et al*. 2007:5). Therefore, the impairment may not be due to methamphetamine-related damage to the areas of the brain associated with visual memory (Moon *et al*. 2007:6). Verbal memory tasks are not as sensitive to executive dysfunction and therefore appear to remain unimpaired, even after methamphetamine exposure.

This is an important aspect of the existing and current research that has clinical implications. If recovering methamphetamine addicts enter rehabilitation with impaired visual memory but unimpaired auditory memory, rehabilitation programmes should perhaps be constructed around the current strengths of the recovering addicts, as opposed to their current weaknesses, and the programme should be more verbally detailed and less visually orientated.

Limitations of the study

It is necessary to interpret all findings in this research within identified limits. Complicating all studies on methamphetamine is the fact that most drugs rarely are used on their own but rather in conjunction with other substances (Gonzalez *et al*. 2007:188). Most methamphetamine addicts are poly-drug users (Barr *et al*. 2006:306) which results in the difficulty to distinguish whether the observed neurocognitive effects are due to methamphetamine specifically or to its interaction with additional drugs.

The length of abstinence in the recovering methamphetamine addicts is another limitation as this study made use of recovering addicts with a minimum of one month of sobriety. The soundness of this research could be improved by using longer term abstinent methamphetamine users in order to fully determine the extent of the impairment in a longitudinal study design. Additionally, the group sizes in this research limit the ability to generalise the findings. The small group sizes are limited due to the resources required to attain the data, and the sensitive nature of the topic researched. Many other studies on methamphetamine and cognition (Johanson *et al*. 2006:327–338; Kalechstein *et al*. 2003:218; McKetin & Mattick 1998:181–184; Moon *et al*. 2007:1–9) suffer from the same limitation, indicating the complex and difficult nature of the research topic.

Finally, although this research did canvass three separate provinces, it was limited by both time and resources to these provinces and is thus not a fully representative study of the South African population.

Recommendations

In view of the results of this research, the study recommends that it would be a valuable undertaking to research the full extent of methamphetamine use in South Africa, in order to establish any province-particular patterns of use or country-specific consequences or recommendations. The relationship between the Western Cape and its high methamphetamine dependence rates, with particular focus placed on the greatest number of methamphetamine users in this province should be of primary concern.

The recognition of the link between methamphetamine use and its link to Human Immunodeficiency Virus (HIV) infection in South Africa should also be explored further. Recognition and knowledge of the risk behaviours of heterosexual and homosexual methamphetamine users

should stimulate prevention efforts that will ultimately help to slow the spread of HIV in the heterosexual population (Semple, Patterson & Grant 2004:810). Indeed, it is believed that effective treatment for methamphetamine addiction and dependence may be one of the most important strategies in reducing the spread of HIV and other, associated communicable diseases (Shoptaw *et al*. 2002).

Finally, to date there are few longitudinal studies concerning the long-term effects of methamphetamine in human beings with particular reference to potential recovery of cognitive functioning. Longitudinal descriptive studies are needed to follow methamphetamine users throughout the course of their use and recovery in order to ascertain the strategies they use to moderate or discontinue their drug abuse (Luna 2001:121). These studies will provide a comprehensive view of the methamphetamine patient and the clinical course of methamphetamine abuse and dependence. Additionally they will aid in determining the extent of cognitive, social, occupational and behavioural recovery and length of time required to achieve this recovery amongst long-term abstinent methamphetamine users. Suggested time periods for these studies are 3, 6, 12 and 24 months abstinence periods.

Conclusion

This research shows that methamphetamine negatively impacts an individual's memory functioning, both in current users and in rehabilitating users, to varying degrees. The cessation of methamphetamine use is met with a marked increase in cognitive impairment in comparison to the cognitive deficit noted in current methamphetamine users. Additionally, this degree of impairment is manifest in comparison to a matched control group.

This research also asserts that the memory functions of short-term visual recall and recognition, learning and retention are increasingly negatively impacted by methamphetamine use, more so than verbal or auditory memory. The impairment in visual learning, retention, recognition and recall as juxtaposed by the lack of deficit in short-term auditory memory has vast implications for the efficacy of traditional literature-based intervention and rehabilitation programmes. These would not be efficacious as the recently sober and recovering addicts would be impaired in their ability to memorise or even retain simple visual information. The majority of information presented in treatment programmes is in literature or coursework form that is provided to them visually. Therefore workshops and seminars, which include much verbal discussion, may be better suited to the rehabilitation situation.

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Competing interest

The authors declare that they have no financial or personal relationship(s) which may have inappropriately influenced them in writing this article.

Author's contributions

C.V.W. (University of Johannesburg) was the project leader, responsible for the study design and execution, and wrote the article; A.D.S. (University of Johannesburg) was responsible for supervision of the research project.

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