Self-regulation and treatment retention in cocaine dependent individuals: A longitudinal study

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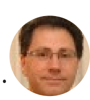
Esperanza Vergara-Moragues
Universidad Internacional de La Rioja

Fermín Fernández Calderón
Universidad de Huelva

Izaskun Bilbao Acedos
Agencia de Servicios Sociales y Dependenci…



Miguel Perez-Garcia
University of Granada

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A. Verdejo-García[a,b,*], P. Betanzos-Espinosa[a], O.M. Lozano[c], E. Vergara-Moragues[d], F. González-Saiz[d,e], F. Fernández-Calderón[c,d], I. Bilbao-Acedos[d], M. Pérez-García[a,b]

[a] *Department of Clinical Psychology, Universidad de Granada, Spain*
[b] *Institute of Neuroscience F. Olóriz, Universidad de Granada, Spain*
[c] *Department of Psychology, Universidad de Huelva, Spain*
[d] *Fundación Andaluza para la Atención a las Drogodependencias e Incorporación Social (FADAIS), Sevilla, Spain*
[e] *Unidad de Salud Mental Comunitaria Villamartín, Unidad de Gestión Clínica Hospital de Jerez, Cádiz, Spain*

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ABSTRACT

Background: We aimed to explore the association between baseline executive functioning and treatment outcome in Therapeutic Communities (TCs).
Methods: We used a longitudinal descriptive design: a baseline neuropsychological assessment was performed within the first 30 days of treatment in TCs. Once participants finished or abandoned treatment, the information about time of stay in treatment was computed for each individual. The study was conducted across six TCs located in the region of Andalusia (Spain): Cartaya, Almonte, Mijas, Los Palacios, La Línea, and Tarifa. Participants were 131 patients with cocaine dependence who initiated and finished treatment in TCs between January 2009 and December 2010 (2 years). Cognitive assessment was composed of general measures of executive functioning: Letter Number Sequencing (working memory) and Similarities (reasoning), and executive tasks sensitive to ventromedial prefrontal cortex dysfunction, including the Delis–Kaplan Stroop test (inhibition/cognitive switching), the Revised-Strategy Application Test (strategy application/multitasking), and the Iowa Gambling Task (decision-making). The outcome measure was retention, defined as time in TC treatment (number of days).
Results: Poor executive functioning significantly predicted shorter treatment retention in cocaine dependent individuals on TC residential treatment (14% of explained variance). Reduced performance on the R-SAT, a multitasking test taxing the ability to develop and apply the best strategy to organize multiple sub-routine tasks in order to achieve a long-term goal, was the most powerful predictor of treatment retention.
Conclusions: Self-regulation deficits predict the capacity to remain in residential treatment among cocaine dependents.

1. Introduction

Addiction is currently conceptualized as a chronic, often relapsing brain disorder that causes compulsive drug use despite harmful consequences to the addicted individual (National Institute of Drug Abuse, 2011). Cocaine and heroin dependence are considered brain disorders in light of evidence of drug-related neuroadaptations in brain systems that are critical for executive control of behavior, with particular relevance of the ventromedial prefrontal cortex, including the medial orbitofrontal cortex, frontal pole, and adjacent anterior cingulate regions (Alia-Klein et al., 2011; Franklin et al., 2002; Langleben et al., 2008; Tanabe et al., 2009). The orbitofrontal cortex is primarily involved in reward-based updating of representations of the affective value of reinforcers (Buckley et al., 2009; Kringelbach, 2005), and therefore it plays a key role in driving behavior according to long-term goals or delayed reinforcers (Bechara, 2005; Sellitto et al., 2010). Adjacent anterior frontal regions, such as the anterior cingulate cortex and medial aspects of the frontopolar cortex (Bechara, 2004), are also relevant to set and follow plans and rules (and inhibiting competitive responses) in order to achieve long-term goals and intentions (Burgess, 2010; Dreher et al., 2008). Although often elusive, the cognitive deficits associated with ventromedial prefrontal cortex dysfunction include strategy application, cognitive switching, and decision-making (Levine et al., 1998; Tranel et al., 2007; Zald and Andreotti, 2010), which are thought to hinder substance use behavior change (Blume and Marlatt, 2009). The persistence of these

* Corresponding author at: Facultad de Psicología, Universidad de Granada, Campus de Cartuja S/N, 18071 Granada, Spain. Tel.: +34 958242948; fax: +34 958243749.
E-mail address: averdejo@ugr.es (A. Verdejo-García).

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deficits may contribute to explain that efforts to develop effective treatment interventions for cocaine and heroin dependence have been frequently unfulfilling (Faggiano et al., 2003; Knapp et al., 2007). Therapeutic communities are one of the most popular treatments for the rehabilitation of drug users in Europe and the United States. Although there is little evidence that TCs offer significant benefits with respect to other psychosocial interventions, there is substantial support to the notion that residential treatment (versus day treatment), and longer retention in treatment are robustly associated with reduced attrition and higher abstinence rates (Simpson et al., 1999; Smith et al., 2006). Therefore, one of the key questions to address in order to improve addiction treatment outcomes is that of which individual differences among addicted individuals are able to predict longer retention in TC treatment.

There is a vast literature about predictors of treatment outcome in cocaine and heroin dependence; relevant predictors can be grouped into socio-demographic factors (such as gender, age, employment or marital status), clinical factors (such as polydrug use, severity of addiction, or comorbid psychopathology), and psychological factors (such as impulsive personality, motivation for treatment, or craving) (Reske and Paulus, 2008). However, none of these factors are by themselves or in combination compelling enough to predict addiction treatment outcomes, so that in the last years there has been a burgeoning interest in using cognitive performance indices to improve prediction of outcomes. As compared to other sources of prediction, cognition offers several advantages, including the assumption that it is more closely associated with the brain neuroadaptations that define the chronic relapsing nature of addiction (Paulus et al., 2005; Sinha et al., 2006), and the evidence that it is able to predict several other factors that impact on treatment outcomes, such as severity of drug use, employment problems or psychiatric comorbidities (Verdejo-García et al., 2006). Accordingly, available studies have shown that cognitive measures, specifically, executive function tests, can significantly predict clinical outcome in cocaine and heroin dependent patients. A range of studies have shown that general measures of cognitive functioning, and specific probes of response inhibition (the Stroop test) and switching (the Wisconsin Card Sorting Test) significantly predict treatment completion in cocaine outpatients (Aharonovich et al., 2003, 2006; Streeter et al., 2008; Turner et al., 2009). Similarly, Passetti et al. (2008) showed that decision-making performance (measured by two different probes using the Iowa Gambling Task and the Cambridge Gamble Task) predicted 3-month relapse in opiate users on community treatment and substitution pharmacotherapy.

The aim of this study was to further explore the association between baseline cognitive functioning and treatment outcome by introducing a number of relevant novelties related to the cognitive testing, and to the population and treatment settings examined. With respect to the cognitive battery, we introduced a number of neuropsychological measures thought to be: (i) more sensitive to probe ventromedial prefrontal cortex related dysfunction (Cato et al., 2004; Li et al., 2010; Levine et al., 1998, 2000), and (ii) more ecologically valid in terms of prediction of adverse life events in addicted individuals (Verdejo-García et al., 2006, 2007). With respect to the treatment setting, we chose to examine outcomes in TCs, which offered a number of methodological advantages above other settings, including the rigorous systematic control of illicit drug-taking and the guaranteed follow-up of all participants. Our targeted sample was formed by patients diagnosed with cocaine dependence, many of which also had regular use of heroin. This substance use pattern was representative of the majority of individuals requesting treatment for drug-related disorders in Europe and the US (EMCDDA Statistical Bulletin, 2010; SAMHSA Treatment Episode Data Set, 2007), a makeup that increased the clinical significance of potential findings. Our main hypothesis was that poor executive control functioning, especially on tests sensitive to ventromedial prefrontal cortex dysfunction, will be associated with shorter treatment retention in TC.

2. Methods

2.1. Design

Longitudinal descriptive. A baseline neuropsychological assessment was performed within the first 30 days of treatment in Therapeutic Communities (TCs). Once participants finished or abandoned treatment, the information about time of stay in treatment was computed for each individual.

2.2. Participants

The targeted population consisted of individuals with a diagnosis of cocaine dependence that initiated and finished treatment in TCs between January 2009 and December 2010 (2 years). To obtain the sample, we defined the sampling context of those patients with cocaine use related disorders who entered treatment on six different TCs located in the region of Andalusia (Spain): Cartaya, Almonte, Mijas, Los Palacios, La Línea, and Tarifa. The six TCs belong to the regional public health care system dedicated to addiction problems, and they all have a common treatment program, based on multidisciplinary interventions including CBT, psychoeducation and occupational therapy, which was originally developed and periodically updated by a clinical committee—formed by clinicians from the different centers (Arenas et al., 2003). Cocaine dependent patients are referred to these TCs from outpatient clinics coordinated by the same public health care network; the main reasons for referral are (i) inability to maintain abstinence during outpatient treatment, and/or (ii) clinicians' or patients' perception of the need of more continuous and intensive treatment. Admissions to TCs are always voluntary, and the allocation of the patients to the different centers is managed by a central computerized information system (https://www.sipasda.info/), which allocates the applicants mainly as a function of space availability.

During the sampling period, between January 2009 and December 2010, a total number of 322 individuals with cocaine use related disorders initiated treatment in these TCs; 286 of these individuals stayed in the TCs for more than 15 days—this was the minimum time of controlled abstinence required to enter the study. The main inclusion criteria to enter the study were: (1) meeting DSM-IV-TR criteria for cocaine dependence, and (2) being able to understand tests instructions and perform the neuropsychological assessment. DSM-IV-TR criteria were determined by the Spanish version of the Psychiatric Research Interview for Substance and Mental Disorders (Torrens et al., 2004). Participants meeting criteria for nicotine dependence or alcohol abuse (but not dependence) were also included. In addition, participants had to meet a minimum abstinence of 15 days; this interval was chosen to avoid potential effects of acute intoxication or withdrawal symptoms on cognitive performance. The mean duration of abstinence at the time of testing was 33.9 days (SD = 21.6). Sixty percent of the patients initiating treatment met these inclusion criteria (n = 172). All these patients were invited to participate in the study, but seven of them refused after reading the explanatory statement. The final sample was formed by 165 patients, of which 131 had finished treatment before December 2010. The remaining 34 patients were still following treatment by December 2010, and therefore they were not included in this study. The distribution of participants by treatment site was: 24.4% from TC Los Palacios, 20.6% from TC Tarifa, 20.6% from TC La Línea, 16.8% from TC Almonte, 13.7% from TC Cartaya, and 3.8% from TC Mijas.

2.3. Instruments

2.3.1. General indices of executive functioning.

Working memory: Letter Number Sequencing (LNS) (Wechsler, 1997): Participants were read a sequence in which letters and numbers are combined, and were asked to reproduce the sequence heard, first placing the numbers in ascending order and then the letters in alphabetical order. The dependent variable from this test was the total number of correct items.

Analogical reasoning: Similarities (Wechsler, 1997): Pairs of words describing common objects or concepts were read, and participants had to indicate how these objects/concepts are similar or what they have in common. The dependent variable from this test was the number of correct items.

2.3.2. Tests sensitive to ventromedial prefrontal cortex functioning.

Response inhibition and switching: Stroop Color-Word Interference Test (CWIT, Delis et al., 2001): We used this paper and pencil version of the Stroop test based on lesion evidence showing its discriminate validity to detect performance deficits associated with ventromedial prefrontal damage (Cato et al., 2004). This test has also shown adequate reliability, and construct validity for the assessment of inhibition and switching skills (Delis et al., 2001). The test consists of four different parts, each containing 50 items. Part 1 (Color Naming) presents patches of colors, and participants had to name them as quickly and accurately as possible. Part 2 (Reading) presents the words "red," "blue" and "green" printed in black ink, and participants had to read aloud these words. Part 3 (Inhibition) introduces the interference effect: the words "red," "blue" and "green" are printed in incongruent colors ink, and participants had to name the color and ignore the word. Part 4 (Switching) has similar items to Part 3, but participants had to switch their response between naming the color of the ink, and reading the word but only in a minority of items that are framed by a box. The main dependent variables derived from this test were the composite time measures: Inhibition vs. Color Naming (time Part 3–time Part 1) and Switching vs. Inhibition (time Part 4–time Part 3).

Self-regulation—Revised Strategy Application Test (R-SAT) (Levine et al., 2000): This is a paper and pencil multitasking test that has shown sound reliability, construct validity (in relation with executive function) (Levine et al., 1998), and discriminate validity in the characterization of skill impairment in different clinical populations with frontal lobe dysfunction (Birnboim, 2011). For this test, participants had to perform three types of simple tasks: figure tracing, sentence copying, and object numbering. Each of these tasks was presented on two different stacks (A and B), each containing 120 items. The main goal of the task was to win as many points as possible, considering that large items scored 0 points, and small items scored 100 points each. However, both small and large items can be of different difficulty: some of them are easy and quick to complete (i.e., they take a couple of seconds, so they are defined as "brief items"), whereas others are very laborious and time-consuming (i.e., they can take longer than 1 min, so they are defined as "lengthy items"). Given the limitation of time (10 min), the most efficient strategy (to-be-discovered) to win the maximum amount of points is to complete only the "brief items" to the exclusion of "lengthy items," which participants must learn to skip as they are introduced in later pages of each stack; this way participants can optimize long-term outcome by completing more items within the time limit. The main dependent variable from the R-SAT was the *proportion of brief items completed* in relation to the total number of items attempted. In addition, there was a secondary instruction forewarning that completion of certain items (e.g., those within pages displaying faces drawings) was penalized with the loss of all the points achieved until that point. Failures to follow this rule (i.e., number of items in pages with faces drawings completed), together with failures to follow the main rule (i.e., number of large items—scoring 0—completed) were added up to compute a measure of inhibitory control—the number of *action slips*.

Affective decision-making: Iowa Gambling Task (IGT) (Bechara et al., 2000): This is a computer task that factors several aspects of decision-making, including uncertainty, risk and evaluation of reward and punishing events. The IGT involves four decks of cards, decks A, B, C and D. Each time a participant selects a card, a specified amount of play money is awarded. However, interspersed among these rewards, there are probabilistic punishments (monetary losses with different amounts). Two of the decks of cards (A and B) produce high immediate gains; however, in the long run, these two decks will take more money than they give, and are therefore considered to be the disadvantageous decks. The other two decks (C and D) are considered advantageous, as they result in small, immediate gains, but will yield more money than they take in the long run. The main dependent variable from this task was the net score for the total 100 trials. We calculated net scores by subtracting the number of disadvantageous choices (decks A and B) from the number of advantageous choices (decks C and D).

2.3.3. Outcome measure. The outcome measure was retention in TC treatment, defined as length of stay in TC (number of days). The fact that the six TCs have a common treatment program and standardized clinical guidelines makes this variable homogeneous across treatment centers. The approximate expected mean stay in these TCs is around 90 days.

2.4. Procedures

After the clinical staff had screened potential participants for inclusion criteria, the selected candidates were informed about the aims of the study and signed an informed consent form if they agreed to participate. The selected participants from the six different TCs were assessed by the same person, a boarded psychologist with a masters in clinical psychology and trained in neuropsychological assessment (P.B.E.). Assessments took place between the days 15 and 30 after onset of TC treatment. Participants were assessed individually in a dedicated room inside each TC. Tests were administered in a fixed order, following standard recommendations for neuropsychological assessment (Lezak et al., 2004). The testing session started around 10 a.m. in the morning and had an approximate duration of 120 min, including a 30-min break to avoid potential effects of fatigue.

2.5. Statistical analysis

We used descriptive statistics to explore the sample characteristics. We explored the normality of the distribution of the different dependent variables using the Kolgomorov–Smirnov test; results showed that all the variables followed a normal distribution. We used partial correlation analyses (using age and education as covariates) to test the association between neuropsychological indices and time in treatment. We applied the Bonferroni correction to adjust the *alpha* level for multiple comparisons in these analyses.

In addition, to test the main hypothesis of the study, the analysis of the predictive capacity of neuropsychological indices on treatment retention, we conducted a hierarchical multiple regression analysis including those measures that previously showed significant correlations with time in treatment. This multiple regression analysis was conducted in SPSS 17.0, and was organized in three different steps by using the "Introduce" method: (step 1) demographic variables, (step 2) general executive control indices, and (step 3) executive control indices sensitive to ventromedial prefrontal cortex functioning. The analysis was set on three steps in order to examine the relative contribution of each of these blocks of predictors (demographic vs. general executive tests vs. ventromedial prefrontal sensitive executive tests), and to estimate if the inclusion of each new block significantly increased the predictive capacity of the model (change in R^2). Potential collinearity effects were tested using specific collinearity diagnoses: Tolerance, the Variance Inflation Factor (VIF), and the Condition Index (Belsey, 1991). Tolerance is the proportion of a variable's variance that is not accounted for by the other independent variables in the equation, whereas VIF is the reciprocal of tolerance. The Condition Index is a measure of the relative amount of variance associated with an eigenvalue. In our data, Tolerance ranged between 0.741 and 0.971, and VIF values ranged between 1.031 and 1.341, all considered adequate. The Condition Index was of 16.193, below the cut-off of 20 proposed by Belsey (1991).

Table 1
Descriptive information for demographic variables, patterns of cocaine and heroin use and neuropsychological performance in the sample (n = 131).

Demographics	
Age	34.3 (7.5)
Gender	
Male	91.5%
Female	8.5%
Years of education	10.5 (1.9)
Patterns of drug use	
Cocaine	
Age at onset	19.4 (6.4)
Age at onset problem use	22.2 (6.7)
Years of regular use	10.5 (5.7)
Frequency of use	
Regulary during weekends	42.7%
Almost everyday	25.2%
Daily use	32.1%
Typical amount per day (g)	0.9 (0.7)
Peak amount per day (g)	2.1 (1.8)
Route of administration	
Oral	0.8%
Sniffed	27.5%
Intravenous	16%
Smoked	54.2%
Inhaled	1.5%
Heroin (n = 96)	
Age at onset	20.6 (6.0)
Age at onset problem use	22.0 (6.3)
Years of regular use	9.4 (6.8)
Frequency of use	
Regulary during weekends	42.6%
Almost everyday	23.4%
Daily use	34%
Typical amount per day (g)	0.33 (0.4)
Peak amount per day (g)	0.67 (0.63)
Route of administration	
Sniffed	2.2%
Intravenous	13%
Smoked	83.7%
Inhaled	1.1%
Methadone maintenance treatment	35.1%
Methadone dose (mg)	41.1 (29.9)
Neuropsychological performance	
Similarities (#correct)	16.6 (4.7)
Letter Number Sequencing (#correct)	8.35 (2.4)
Stroop-Inhibition (time Part 3–time Part 1, s)	26.4 (11.8)
Stroop-Switching (time Part 4–time Part 3, s)	39.5 (16.8)
IGT (net score)	−3.19 (24.1)
R-SAT (proportion of brief items)	77.56 (8.6)
R-SAT (number action slips)	3.81 (4.5)

Note: Numbers express means and (standard deviations) for quantitative variables and percentages for qualitative variables.

3. Results

3.1. Sample characteristics

We provide the descriptive information about patterns of cocaine and heroin use in Table 1; data includes age at onset,

Table 2
Inter-correlations (Pearson coefficients) between performance on neuropsychological tests and time in treatment using age and years of education as covariates.

	Time in Tx	Similarities	LNS	Stroop-I	Stroop-S	IGT
Similarities	0.172*					
LNS	0.061	0.366**				
Stroop-I	−0.193*	−0.168*	−0.302**			
Stroop-S	−0.202*	−0.182*	−0.248**	0.407**		
IGT	0.027	0.022	−0.080	0.008	−0.042	
R-SAT	0.209**	0.007	0.148*	−0.014	−0.167*	0.091

Note: Tx: treatment, LNS: Letter Number Sequencing, Stroop-I: Stroop-Inhibition, Stroop-S: Stroop-Switching, IGT: Iowa Gambling Task, R-SAT: Revised-Strategy Application Test.
* $p < 0.05$.
** $p < 0.01$.

amount, frequency and duration of use, and routes of administration. Table 1 also provides descriptive information about performance on neuropsychological tests.

3.2. Descriptive information about therapeutic variables

The mean time of stay in treatment in the whole sample was of 137.11 days (SD = 63.2); there were significant differences between the patients who finished treatment and were released by the clinical staff (60.3% of the sample), and the patients who abandoned treatment before discharge (39.7% of the sample). The first subgroup had a mean stay of 187.46 days (SD = 42.81), whereas the latter subgroup stayed for a mean of 103.96 days (SD = 51.59); $t = 9.679$, *d.f.* = 129, $p = 0.000$. There were no significant differences on the time of stay in treatment as a function of gender or age; however, we found that those patients with greater years of education stayed longer in treatment, $r = 0.186$, $p = 0.034$. With regard to patterns of drug use, there were no significant differences in time of stay in treatment as a function of the co-use of heroin, enrollment on methadone treatment, methadone dose, or duration of abstinence of cocaine or heroin.

3.3. Association between demographic and drug use variables and neuropsychological performance

There were no differences on neuropsychological performance as a function of gender. Age was significantly correlated with performance on Stroop-Inhibition, $r = 0.215$, $p = 0.014$, and R-SAT, $r = 0.238$, $p = 0.006$. There were also statistically significant associations between years of education and performance on Similarities, $r = 0.386$, $p = 0.000$, Letter Number Sequencing, $r = 0.205$, $p = 0.019$, Stroop-Inhibition, $r = -0.186$, $p = 0.034$, and Stroop-Switching, $r = -0.237$, $p = 0.006$. There were no significant differences on performance as a function of the co-use of heroin, with the exception of Stroop-Inhibition scores, $t = -2.874$, *d.f.* = 129, $p = 0.005$, where cocaine–heroin users performed poorer than cocaine users without heroin co-use. Furthermore, there were no differences on performance as a function of enrollment on methadone pharmacotherapy, or significant associations between methadone dose and neuropsychological performance.

3.4. Neuropsychological predictors of length of stay in treatment

Partial correlation analyses showed that patientsǐ performance on Similarities, $r = 0.172$, $p = 0.026$, Stroop-Inhibition, $r = -0.193$, $p = 0.014$, Stroop-Switching, $r = -0.202$, $p = 0.011$, and R-SAT, $r = 0.209$, $p = 0.008$, were significantly associated with retention in treatment (Table 2). However, after applying the Bonferroni correction, only the correlation with R-SAT was still statistically significant (see Fig. 1).

All the variables showing significant associations with treatment retention (uncorrected partial correlations) were included in a hierarchical multiple regression analysis; this analysis was set in three steps, corresponding to the three blocks of predictors: (1) demographic variables (years of education), (2) general executive indices (Similarities), and (3) executive control indices sensitive to ventromedial prefrontal cortex function (Stroop and R-SAT). Results showed that the change in the explained variance was only significant when the third block of predictors was included. The model including years of education (step 1) explained a 3.4% of the variance. The second model, after inclusion of Similarities (step 2), explained a 6.6% of the variance. Finally, the third model, after inclusion of Stroop and R-SAT (step 3), explained a 14.1% of the variance, producing a significant change in the *F* value of the full model, *Change in F* = 5.100, $p = 0.007$. The only significant predictor variable in this third bock was performance on the R-SAT (Table 3).

This model was subjected to validation by re-running analyses after randomly selecting a 75% of the sample. Results were equivalent to those found in the total sample. The significant change in explained variance occurred after inclusion of the third block, *Change in F* = 5.378, $p = 0.006$. Among predictor variables, only R-SAT performance showed a statistically significant coefficient, $\beta = 2.103$; $t = 3.064$; $p = 0.003$.

4. Discussion

This study demonstrates that poor executive functioning moderately predicts shorter treatment retention in cocaine dependent individuals on TC residential treatment. Demographics and executive indices together predicted a 14% of total explained variance in retention time, which can be regarded as a mild effect. However, we stress the finding that reduced performance on the executive tests sensitive to ventromedial prefrontal cortex dysfunction was

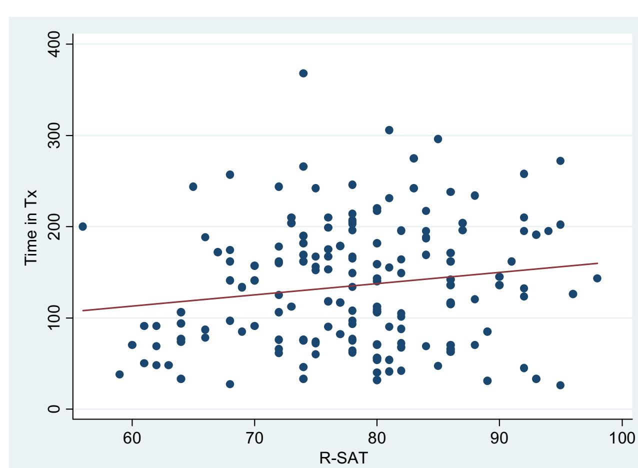

Fig. 1. Relationship between R-SAT performance–percentage of brief items (*X* axis) and time in treatment (*Y* axis).

Table 3
Final model prediction of time in treatment including demographic, general executive indices and orbitofrontal-related executive indices.

Predictors	Beta	S.E.	*T*	*p*	Confidence intervals	Tolerance	FIV
Years of education	2.517	2.933	0.858	0.392	−3.288 to 8.322	0.826	1.210
Similarities	2.039	1.221	1.670	0.097	−0.377 to 4.456	0.820	1.219
Stroop Inhibition	−0.615	0.503	−1.223	0.223	−1.610 to 0.380	0.781	1.280
Stroop Switching	−0.317	0.361	−0.877	0.382	0.398–0.746	0.746	1.341
R-SAT	1.590	0.620	2.566	0.011	0.364–2.817	0.970	1.031
Constant	−17.569	61.601	−0.285	0.776	−139.486 to 104.348		

Note: R-SAT: Revised-Strategy Application Test.

the most powerful predictor of treatment retention, duplicating the predictive capacity of demographics and general executive function indices. The individual index with greater impact on treatment retention was the R-SAT, a multitasking test sensitive to impairment on strategy application skills relevant to adjust multiple tasks performance towards a primary goal.

Our findings are in agreement with growing evidence about the significant impact of executive dysfunction on treatment outcomes in substance dependent individuals (Blume and Marlatt, 2009). In agreement with previous findings in cocaine dependent outpatients, we found a moderate role of reasoning (Similarities), inhibition and switching (Stroop) skills on treatment retention (Aharonovich et al., 2003, 2006; Turner et al., 2009). On top of these results, we showed that strategy application deficits may hinder change in addiction recovery even within very well controlled settings where psychological support is continuous and exposure to stress and conditioned drug cues is negligible—as compared to real-life scenarios. Although ours and others' findings suggest that the effect of cognitive performance on treatment outcomes is relatively mild, we should stress that, unlike other similarly relevant predictors, such as psychiatric-related stress or employment status (Peirce et al., 2009), executive deficits are not typically targeted during psychosocial treatment. Therefore, our results stress the potential benefits of incorporating cognitive rehabilitation strategies to the repertoire of treatment tools currently applied for addiction treatment, as they could effectively address cognitive impairments deterring treatment success (Alfonso et al., 2011; Bickel et al., 2011).

An important novelty of our results is the finding that the tests sensitive to ventromedial prefrontal cortex dysfunction, CWIT Stroop and R-SAT (Cato et al., 2004; Tranel et al., 2007), were the most powerful set of measures predicting treatment retention in our sample. This finding is in agreement with evidence that ventromedial prefrontal cortex dysfunction is rather persistent among psychostimulant dependent individuals: performance deficits remain up to 1 year after cessation of drug use, according to available studies using sensitive neuropsychological probes (Verdejo-García et al., 2007), and brain alterations last up to 4 years after cessation of drug use as revealed by long-lasting gray matter reductions in this region (Tanabe et al., 2009). These alterations may, therefore, importantly impact change in substance use behavior and treatment success even after protracted periods of abstinence. The role of strategy application deficits, taxed by the R-SAT, might be of particular relevance considering that: (1) it captures the inability to bypass environmental cues and internal habits that oppose the most efficient strategy to achieve a long-term goal (Levine et al., 2000), a deficit that resembles the negative implications of premature treatment cessation for full remission (Simpson et al., 1999; Smith et al., 2006), and (2) it is specifically designed to optimize the ecological validity of neuropsychological assessment, since ecologically valid tests are significantly more predictive of everyday behavioral problems among substance dependent individuals (Verdejo-García and Pérez-García, 2007).

On the other hand, one of the selected probes of ventromedial prefrontal cortex dysfunction (the IGT) was not predictive of treatment retention, somehow inconsistent with studies showing that IGT performance can reliably predict drug relapse (Bowden-Jones et al., 2005; Passetti et al., 2008). Nonetheless, these latter results have been tempered by preliminary findings showing that IGT deficits are strong predictors of abstinence rates in opiate outpatients, but not predictive of abstinence rates in patients following residential treatment (Passetti et al., 2011). Several factors may account for the lack of predictive capacity of IGT on treatment retention. One relevant issue is the fact that decision-making skills significantly improve during residential treatment (Aklin et al., 2009); therefore, their relative impact is undermined as retention in treatment increases. Alternatively, it might be the case that decision-making skills are not as important for cocaine dependence treatment as they are for interventions for alcohol and opiate addiction, the drug-using samples in which decision-making deficits have been found to predict relapse. This notion would be consistent with evidence showing that alterations in cognitive switching and perseveration (like those measured by R-SAT and Stroop Switching) are more robust, and potentially more significant in relation to treatment outcomes among cocaine patients (Ersche et al., 2008; Woicik et al., 2011). A third relevant point is the discrepancy between outcome variables: IGT studies have linked performance in this task with drug relapse during community treatment (Passetti et al., 2008), or after residential treatment (Bowden-Jones et al., 2005), whereas our study relates executive function with retention across residential treatment. It is likely that decision-making skills become more relevant when cocaine dependent patients go back to the community and have to withhold drug seeking in the face of multiple cues and stressors.

Our study has several important strengths including the relatively large sample size (the largest reported so far among this type of studies), the representativeness of the sample, the precise monitoring of retention rates, and the adequate control of relevant confounding variables, such as exposure to drug cues or illicit drug-taking within the TC settings. Furthermore, most of the previous studies on the topic had been conducted on cocaine outpatients who were simultaneously enrolled in clinical trials testing the effects of different pharmacotherapies. Conversely, our study was specifically designed to test the impact of executive dysfunction over retention on residential multimodal treatment. Limitations include the relatively heterogeneous makeup of substance use patterns, including both primary cocaine dependence and cocaine–heroin co-use—on top of nicotine and alcohol use, or the indirect nature of our outcome variable, i.e., retention is a reliable and robust indicator of treatment success, but other outcome measures, such as drug relapse, may have greater face validity and overall significance for long-term addiction treatment prognosis. The addition of more general predictor variables, such as IQ, may also contribute to increase the predictive capacity of regression models. A follow-up study in this same sample is currently attempting to address some of these shortcomings.

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Contributors

AVG, MPG, OL and FGS designed the study. PBE and EVM participated in the assessment protocols design and administration. OL, FLC and IBA conducted statistical analyses. AVG developed a first draft of the manuscript that was supervised by all authors.

Conflict of interest

The authors declare that, except for income received from their primary employer, no financial support or compensation has been received from any individual or corporate entity over the past 3 years for research or professional service and there are no personal financial holdings that could be perceived as constituting a potential conflict of interest.

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