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Computer-Assisted Cognitive Rehabilitation for the Treatment of Patients With Substance Use Disorders: A Randomized Clinical Trial

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The purpose of this study was to examine the comparative efficacy of cognitive rehabilitation as an intervention for substance misuse. Patients with substance use disorders entering long-term residential care ($N = 160$) were randomly assigned to one of two conditions: (a) standard treatment plus computer-assisted cognitive rehabilitation (CACR), which was designed to improve cognitive performance in areas such as problem solving, attention, memory, and information processing speed; and (b) an equally intensive attention control condition consisting of standard treatment plus a computer-assisted typing tutorial (CATT). Participants were assessed at baseline, during treatment, at treatment completion, and 3-, 6-, 9-, and 12-month follow-up. Intent-to-treat analyses showed that, compared with those randomized to CATT, patients who received CACR were significantly more engaged in treatment (e.g., higher ratings of positive participation by treatment staff, higher ratings of therapeutic alliance), more committed to treatment (e.g., longer stays in residence) and reported better long-term outcomes (e.g., higher percentage of days abstinent after treatment). Mediational analyses revealed the positive comparative effect of CACR on abstinence during the year after treatment was mediated by treatment engagement and length of stay in residence.

Keywords: substance abuse, cognitive rehabilitation, randomized control trial, mediation, treatment outcome

There is now ample evidence from multiple lines of research that chronic abuse or long-standing dependence on psychoactive substances is associated with neuroanatomical changes that appear to give rise to discernable cognitive impairments (e.g., Tanabe et al., 2007; Bolla, Eldreth, Matochik, & Cadet, 2005). The most commonly described neurocognitive profile for individuals who chronically abuse or are dependent upon alcohol generally is that they preserved verbal learning skills and vocabulary, but have measurable deficits on tests of problem-solving, conceptual shifting, perceptual-spatial skills, abstract reasoning, motor speed, information-processing speed, and memory (e.g., Fals-Stewart & Bates, 2003). Although comparable programmatic research with individuals who primarily use drugs other than alcohol is less evolved, available evidence reveals that cognitive impairment similar to that observed among alcoholic patients is associated with chronic use of cocaine, heroin, sedative hypnotics, solvents, and multiple drugs in combination (for a review, see Vik, Cellucci, Jarchow, & Hedt, 2004). The degree of impairment associated with substance use disorders (SUDs) can vary greatly, ranging from comparatively mild to being as severe as that resulting from traumatic brain injury (Bates, Pawlick, Tonigan, & Buckman, 2006; Victor & Adams, 1985). As a consequence of how it is operationalized and the neuropsychological tests used, prevalence estimates of cognitive impairment among patients with SUDs vary widely, ranging from 30% to 80% (e.g., Bates & Convit, 1999; Meek, Clark, & Solana, 1989; Parsons & Nixon, 1993; Rourke & Loberg, 1996).

Based on the conclusions of a large and growing body of empirical research, the presence of cognitive deficits among substance-abusing patients has important clinical implications. Fundamentally, counseling and other forms of therapy involve both formal and self-directed learning tasks, requiring patients to receive, encode, and integrate new information that is presented during treatment, to organize this information into behavioral plans, and to initiate and execute these plans. Regardless of theoretical orientation, the vast majority of psychosocial treatments for substance use disorders (e.g., 12-step facilitation, motivational interviewing, cognitive–behavioral therapy) are verbally based interventions that require extensive cognitive processing by patients to facilitate cognitive and behavioral change (Goldman, 1990; Weinstein & Shaffer, 1993). Although individual or group therapy sessions may appear to have a simple

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and clear presentation, when viewed from a learning perspective, patients are required to utilize a complex set of executive cognitive functions. For example, working memory skills are needed that facilitate acquisition and recall of new health information, and initiation and planning skills are needed to organize this information into a behavior change plan. The newly learned health information and behavior plans must be retrieved and applied at the necessary times outside of treatment toward more healthful behavioral responses, and interference control is needed to discriminate and inhibit irrelevant stimuli, both external and internal, that may interfere with the organization and execution of the behavior plan. Unfortunately, the presence of cognitive impairment is likely to interfere with this learning and using of new information and, in turn, to be associated with poorer treatment response and long-term outcomes.

There is growing empirical support for this conceptualization of how the presence of cognitive impairment may affect treatment. More specifically, cognitive impairment among patients with SUDs is associated with poorer treatment response, including (a) lower treatment adherence (Bates et al., 2006), (b) greater frequency of treatment program rule violations (Fals-Stewart, 1993), (c) lower likelihood of successful program completion (Fals-Stewart & Schafer, 1992), (d) slower acquisition of drink refusal skills (Smith & McCrady, 1991), (e) lower levels of treatment engagement (Katz et al., 2005), (f) less readiness to change (Blume, Schmaling, & Marlatt, 2005), (g) lower self-efficacy (Bates et al., 2006), (h) decreased insight (Horner, Harvey, & Denier, 1999; Shelton & Parsons, 1987), and (i) increased denial of substance use severity and associated problems (Rinn, Desai, Rosenblatt, & Gastfriend, 2002). Relatedly, several investigations have found that cognitive impairment is associated with poorer substance abuse treatment outcomes, including decreased treatment retention (Aharonovich, Hasin, Brooks, Liu, Bisaga, & Nunes, 2006; Donovan, Kivlahan, Kadden, & Hill, 2001; Fals-Stewart, 1993; Fals-Stewart & Schafer, 1992) and less abstinence from substances of abuse after treatment has ended (Aharonovich et al., 2006).

Given the high prevalence of cognitive impairment among patients with SUDs, as compounded by the link between these impairments and treatment response and outcome, many have recommended that interventions for substance abuse address or otherwise account for patients' cognitive functioning. The specific causal role of neurological changes associated with these cognitive impairments, or the role they may play in treatment outcomes, is not yet clear. However, interventions may be able to ameliorate the cognitive impairments to improve treatment outcomes. One approach that appears particularly promising is cognitive rehabilitation. Cognitive rehabilitation interventions consist of various exercises designed to enhance such cognitive skills as problem-solving, attention, memory, abstract reasoning. If effective, cognitive rehabilitation could ultimately enhance the ability of patients with SUDs to receive, encode, integrate, retrieve, organize, and use more healthful information garnered during the course of treatment (regardless of the type of treatment received).

Consistent with this notion, it has been posited that the therapeutic action of cognitive rehabilitation with patients that have SUDs may work in the form of a "causal chain" where its effects on positive outcome are not direct, but operate primarily "through" helping to improve general response to therapy. In such a model, participation in cognitive rehabilitation would lead to better treatment engagement (e.g., stronger therapeutic alliances, increased positive participation in treatment) because patients would be more able to learn and use information presented as part of therapy, and as such, be able to engage more effectively with providers in therapy and with different aspects of the program more broadly (e.g., following rules). Better treatment engagement would lead to a stronger commitment to treatment, as evidenced by longer stays in treatment and successful completion. Lastly, longer stays in treatment would lead to better posttreatment outcomes; length of stay has long been associated with better substance abuse outcome (Teesson et al., 2006; Zhang, Friedmann, & Gerstein, 2003).

Results from preliminary investigations have supported the positive neuropsychological and therapeutic effects of cognitive rehabilitation for patients with SUDs, although no study to date has been able to test simultaneously the elements of this causal chain model. For example, Fals-Stewart and Lucente (1994) recruited cognitively impaired patients with SUDs ($N = 141$) from a long-term (i.e., 12-month) residential care facility who were mandated by the criminal justice system to remain in treatment. Those randomly assigned to received computer-assisted cognitive rehabilitation (CACR) showed significantly greater positive acceleration in cognitive performance on neuropsychological tests during the first several months of treatment than residents assigned to control conditions (i.e., computer-aided typing, progressive muscle relaxation, or treatment-as-usual). This is consistent with other studies that have shown that cognitive rehabilitation does accelerate amelioration of cognitive impairments among patients with SUDs (e.g., Goldstein, Haas, Shemansky, Barnett, & Salmon-Cox, 2005). Compared with controls, patients who received CACR were also rated as more positively engaged in the treatment by program staff.

The participants recruited for the Fals-Stewart and Lucente (1994) study were an extremely select group, consisting of cognitively impaired patients with SUDs who could not leave treatment. This allowed the investigators to ascertain whether or not the cognitive rehabilitation exercises were having the intended effects (i.e., leading to improved cognitive functioning as measured by repeated administration of neuropsychological tests) without concerns for confounding interpretation of results because of high or differential drop out. The investigation also allowed for examination of the effect of cognitive rehabilitation on a measure of treatment engagement. However, participants in this study were highly atypical because most substance-abusing patients in residential care are not under such severe legal restrictions and can drop out of treatment, leading to variation in length of stay. Thus, the investigators could not examine the effects of CACR on length of residence in treatment.

Another important limitation of the Fals-Stewart and Lucente (1994) study was that only cognitively impaired substance-abusing patients were recruited for the investigation. However, it is plausible that cognitive rehabilitation would have positive effects for all patients, not just those classified as impaired on a neuropsychological test battery. As an analogy, exercise is considered to be healthful to those individuals who are very physically unfit, but it is also healthful to individuals across a broad range of fitness levels (e.g., mild to moderate levels of poor fitness). Although many substance-abusing patients would not be classified as cognitively impaired on a comprehensive neuropsychological test battery, this does not indicate their cognitive functioning is fully intact (Lee et al., 2006; Winblad et al., 2004). On many neuropsychological test batteries, individuals must have very poor test performances to be classified as impaired. Yet, those who score above the cutoffs may also not be functioning optimally (i.e., they have mild or subclinical deficits) and could, indeed, benefit from cognitive rehabilitation. If cognitive rehabilitation were found to be generally beneficial for patients with SUDs, the intervention would have far broader applicability and appeal because then its use would not require identification of cognitively impaired patients with what are often lengthy neuropsychological testing batteries. In turn, some have called for cognitive rehabilitation studies that include all substance-abusing patients, not just those whose cognitive functioning falls below a threshold which places them in the category of being impaired (National Institute on Drug Abuse, 2003).

To address some of these concerns, Grohman and Fals-Stewart (2004) recruited 120 patients with SUDs from a 12-month residential treatment program, consisting of both cognitively impaired and unimpaired patients, and randomly assigned them to either CACR or control conditions (i.e., computer-aided typing or treatment as usual). For both cognitively impaired and unimpaired patients, those who received CACR were more committed to treatment, as evidenced by longer residential stays, and were more likely to graduate successfully from the program. Posttreatment follow-up assessments (i.e., 6 months after program discharge) revealed those who received CACR had a significantly greater percentage of days abstinent after treatment than those in the other conditions. However, the investigation did not collect measures of treatment engagement and was underpowered to test any mediation effects adequately (which, of course, are implicit in the causal chain model described earlier).

Although the results from the cognitive rehabilitation studies described thus far are promising, these investigations are limited by one or more of the following methodological limitations: (a) recruitment of atypical and highly select patients, greatly limiting generalizabilty, (b) examination of effects only among cognitively impaired patients, (c) lack of posttreatment assessments or, if conducted, evaluated only a comparatively brief time window after treatment, and (d) insufficient power to examine mediation effects. The purpose of the present study is to address these limitations and examine the comparative efficacy of CACR as an intervention for substance abuse in the context of a sufficiently powered longitudinal randomized control trial. The investigation was also designed to test the causal change model described earlier: CACR à improves treatment engagement à increases commitment to treatment (evidenced by longer treatment stays) à better posttreatment outcome. Thus, it is hypothesized that, compared to an attention control treatment, those who receive CACR will demonstrate better treatment outcomes, but that this effect will work "through" treatment engagement and treatment commitment. In turn, it is also hypothesized that those who receive CACR, compared with a control intervention, will have better treatment engagement (e.g., more positive participation in treatment, stronger therapeutic alliance), leading to a stronger commitment to treatment as evidenced by longer stays in residential treatment.

Method

The investigation used a hybrid model research design (Carroll & Rounsaville, 2003) that included elements of a carefully implemented efficacy trial (e.g., diagnostic assessment, clinicians and research assistants unaware of the a priori hypotheses, randomization to conditions, multiple longitudinal standardized assessments) coupled with aspects that replicate "real-world" conditions (e.g., the conduct of the study in a community-based treatment program, broad inclusion criteria for program admission). All procedures were reviewed and approved by the University of Rochester institutional review board, and all participants were given written informed consent. A certificate of confidentiality, issued by the National Institute on Drug Abuse, was also obtained. Rigorous quality assurance, including careful data monitoring, were in place throughout the course of the study to ensure data collection integrity.

Participants

Participants were male and female patients with SUDs admitted to a 6-month residential treatment program. To be eligible for admission to this program, individuals had to be at least 18 years of age and had to have met *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM–IV–TR*; American Psychiatric Association, 2000) criteria for one or more substance use disorders (excluding nicotine and caffeine). Individuals were not eligible for admission if they had advanced stage medical disease as indicated by global physical deterioration, a significant risk of suicidal/homicidal intent, a history of schizophrenia-spectrum diagnosis, a history of active (past 2 months) psychosis, or could not speak English. Those patients who were enrolled in the program were not eligible to participate in the investigation if they did not stay in residence for at least 1 week or did not give informed consent.

Procedures

Design. This study used a randomized, controlled, repeated measures design to assess the efficacy of CACR plus standard substance abuse treatment in comparison to an equally intensive active attention control treatment, computer-assisted typing tutorial (CATT), plus standard substance abuse treatment. After baseline assessment, participants were randomly assigned to one of the two conditions consisting of three sessions per week for the first 8 weeks of during the 6-month treatment period. Participants were assessed monthly during treatment, as well as at the end of treatment and 3, 6, 9, and 12 months' posttreatment.

Recruitment and baseline assessment. The investigation was advertised through brochures and fliers in the treatment program. Within 48 hours of program admission, research personnel invited interested patients to schedule final screening and consent interviews. These interviews were scheduled 7 days after program admission (as recorded in patients' medical records). Eligible and consenting patients also participated in the initial baseline interview at that time to gather information on substance use, general addiction severity and psychosocial adjustment, and cognitive functioning. These interviews last between 2.5 and 3 hours. Research assistants, who remained unaware of randomization assignment, conducted all baseline and posttreatment interviews. After completion of the baseline interview, participants were randomly assigned to either CACR or CATT. The presence of cognitive impairment as identified by the Neuropsychology Assessment Battery-Screening Module (Stern & White, 2003) (see *Measures*) was used in a covariate-adaptive urn randomization procedure.

During-treatment and posttreatment evaluations. Following completion of CACR and CATT sessions nine weeks after the baseline interview, a during-treatment evaluation was conducted to assess patients' cognitive functioning, counselors' ratings of therapeutic alliance, counselors' ratings of patients' participation in treatment, participants' satisfaction with treatment services. At the end of treatment in the residential program, type of discharge was determined from medical records (i.e., successfully completed or not). At the completion of treatment and at 3, 6, 9, and 12 months thereafter, participants were interviewed about their substance use and other aspects of psychosocial adjustment.

Compensation. Participants received $100 for baseline assessments. They received $20 for 9-week within-treatment assessment and $50 for follow-up assessments at discharge, 3, 6, 9, and 12 months' posttreatment.

Treatments. Patients randomly assigned to CACR engaged in cognitive rehabilitation exercises using PSS CogReHab (Psychological Software Services Inc., 1989, 2003, 2003). PSS CogReHab is a software package consisting of four modules that aim to improve functioning in a variety of executively governed domains: (a) the *Foundations* module teaches visual and auditory reaction time; visual discrimination; tracking and targeting tasks to train basic executive functions involving focusing, shifting, sustaining, and dividing attention; discrimination; initiation; inhibition; and differential responding; (b) the *Visuospatial* module teaches complex attention skills through the use of mazes and visual perception and construction tasks; (c) the *Problem Solving* module includes tasks that involved number manipulations, mazes, and deductive exercises to teach problem-solving skills in a variety of different conditions; and (d) the *Memory* module presents tasks requiring spatial, visuospatial, sequencing, and nonsequencing tasks to address recall memory, memory of incidental information, and memory of information occurring in multiple stimulus situations. Each module adapts to the individual's performance; thus, for participants who perform well on a given program (i.e., few errors and sufficient speed), the particular task will increase in difficulty. Participants will move through the same fixed sequence of modules. Each module requires participants to remain with a given task until sufficient mastery has been achieved. There would be methodological advantages to standardizing the programs such that participants would receive the same exposure to the same exercises. However, that is contrary to the cognitive rehabilitation paradigm, which is founded on the notion that rehabilitation should adapt to the participants' strengths and limitations (e.g., Wilson, Herbert, & Shiel, 2003). In many important respects, this is not different from therapy in general or even manualized therapies. Counselors naturally adapt and change psychosocial interventions, even highly structured, manualized ones, to the needs and problems of the given patient. CACR participants completed three 50 minute sessions per week for 8 weeks. All sessions were supervised by program staff to ensure participants were engaging in the computer-assisted exercises.

Participants randomly assigned to the CATT condition participate in 50-min sessions of typing training three times per week for 8 weeks, a dose comparable to the CACR condition. In a supervised format, CATT participants were required to copy words that are shown in the top half of the screen to the bottom half of the screen. After completing the exercise, participants received computer-generated feedback regarding their typing speed and accuracy. The typing segments were drawn from the Typing Master ProTrainer (2002; Typing Master Pro). This control condition has been used in previous studies of cognitive rehabilitation of adult substance-abusing individuals (e.g., Fals-Stewart & Lucente, 1994; Grohman & Fals-Stewart, 2003). In these studies, residents who participated in the computerized control condition did not receive any additional benefit beyond that of treatment-as-usual (TAU). As with the CACR condition, a member of the research staff was in the room to clarify any instructions that were unclear, to address and correct technical problems, and to ensure that participants engaged in the exercises as instructed.

In addition to participation in CACR and CATT, all participants received the standard treatment provided by the residential treatment program. The program adhered to what is typically referred to as the Minnesota Model of substance abuse treatment, founded upon the tenets of Alcoholics Anonymous (see Anderson, 1981, and Stinchfield & Owens, 1998, for a comprehensive description and evaluation, respectively). The majority of residential treatment programs in the United States reportedly adhere to the

Minnesota Model philosophy of substance abuse treatment. Upon admission, residents were given a general orientation to the program and were expected to learn facility rules and program philosophy. They were also assigned to an individual therapist, with whom they were scheduled to meet two times per week. They were also required to attend 90-min group therapy sessions three times per week. Additional components of the program include self-help meetings (e.g., Alcoholics' Anonymous and Narcotics Anonymous meetings) and educational classes on substance abuse, HIV/AIDS risk behaviors, and gender issues. Participation in CACR or CATT did not interfere with their participation in standard care.

The counselors in the program ($n = 9$) who conducted the standard individual and group therapy treatments for study participants were all certified substance abuse treatment providers who either had Bachelor- or Masters-level education, with a mean (*SD*) number of years of experience as treatment counselors of 7.5 (5.2).

Measures

Cognitive functioning. The Neuropsychological Assessment Battery-Screening Module (NAB-SM) (Stern & White, 2003) assesses cognitive functioning across five domains: attention, language, memory, visuospatial, and executive (see Table 1). Administration time is approximately 45 min. The NAB-SM has been recommended for use with SUD patients because of its sensitivity (.81) and specificity (.92) in classifying patients with present or absent cognitive impairment in this population (Grohman & Fals-Stewart, 2004). Decision classifications using the NAB-SM were based on the dichotomous Total Screening Index (TSI). The TSI is a composite measure of the five cognitive domain scores, and is a standardized score representing the examinee's overall test performance. TSI values less than or equal to 84 (corresponding to a score of more than 1 *SD*, or 15 points, below the mean of 100) are indicative of cognitive impairment. Test norms were demographically corrected relative to a standardization sample ($N = 1{,}448$) of neurologically healthy individuals of the same age, sex, and educational level (Stern & White, 2003).

The North American Adult Reading Test (NAART; Blair & Spreen, 1989) is a reading test of 61 irregularly spelled words (e.g., debris, psalm, caveat) printed in two columns on both sides of an 8 × 11 in. card, which is given to the examinee to read aloud. Each pronunciation error is counted as 1 point; the cumulative number of errors is entered into an equation to provide a lower bound estimate of an examinee's premorbid IQ (Stabbing, Wilson, Filley, Bernard, & Fox, 1990).

Table 1
Sociodemographic, Background, and Diagnostic Characteristics of Participants

	CACR ($N = 80$)				CATT ($N = 80$)			
Characteristic	*M*	*SD*	*n*	%	*M*	*SD*	*n*	%
Age (in years)	32.4	7.1			33.1	6.8		
Years of education	12.9	1.4			12.7	1.6		
Male			46	58			48	60
Race/ethnic composition								
African American			22	28			24	30
Caucasian			43	54			40	50
Latina			8	10			7	9
Multiracial			5	6			5	6
Other			3	4			4	4
Marital status								
Married			14	18			12	15
Single			50	63			51	64
Divorced/separated			16	20			17	21
Prior alcohol/drug treatment episodes	2.9	2.0			3.1	2.4		
Current *DSM–IV* substance abuse or dependence diagnosis								
Alcohol			59	74			56	70
Cannabis			17	21			19	24
Cocaine			20	25			24	30
Opiate			21	26			23	29
Stimulant			27	34			25	31
Polydrug			26	33			24	30
Other			20	25			17	21
Percentage of days abstinent in previous 12 months	32.0	28.6			29.9	29.4		
Premorbid IQ	104.4	8.9			103.6	9.1		
Cognitively impaired			25	31			27	34

Note. CACR = computer-assisted cognitive rehabilitation; CATT = computer-assisted typing tutorial; *DSM–IV* = *Diagnostic and Statistical Manual of Mental Disorders* (Fourth Edition). Premorbid IQ based on results from the North American Adult Reading Test. Participants were classified as "cognitively impaired" if they received a *T* score of less than 40 on the Neuropsychological Screening Battery–Screening Module (NAB-SM). Percentage of days abstinent was derived from the Timeline Followback Interview.

Substance use. The Timeline Followback Interview (TLFB; Sobell & Sobell, 1996) uses a calendar and other memory aids to determine an individual's drinking and other drug use over a specified time period. The substance use index derived from the TLFB used in the present investigation was *percent days abstinent* (PDA), which was operationally defined as the percentage of days in the measurement interval that the substance abusing patient did not drink or use illicit drugs and was not in jail or a hospital for reasons related to substance use. The TLFB has been shown to have excellent reliability and validity for collection of substance use frequency information (Fals-Stewart, O'Farrell, Freitas, McFarlin, & Rutigliano, 2000).

Each participant was interviewed separately with substance use modules of the *Structured Clinical Interview for DSM–IV* (SCID; First, Spitzer, Gibbon, & Williams, 1995), administered by one of two trained master's-level interviewers. Interrater reliability was assessed using a paired-rater design. Audio-taped interviews of 30 randomly selected patients entering this study were independently coded by both primary interviewers and by the first author. Agreement among the evaluators was excellent, with kappas ranging from .0.9 to 1.0 for the substance use disorders.

The Addiction Severity Index (ASI; McLellan et al., 1992) is an assessment instrument designed to be administered as a semistructured interview in one hour or less to patients who present for substance abuse treatment. The instrument gathers information about seven areas of a patient's life: medical, employment/support, drug and alcohol use, legal, family history, family/social relationships, and psychiatric problems. Composite scores for each area were calculated; these are based on weighted combinations of individual items that provide reliable, valid, and sensitive measures of problem severity. Composite scores range from 0 to 1.0, with higher scores indicating greater impairment. The ASI was administered at baseline and 12-month posttreatment follow-up only.

Biologically confirmed abstinence from drugs of abuse was obtained by use of the SureStep urine drug screen card, a rapid test for the detection of 10 different drugs and drug metabolites in human urine. Recent alcohol use was tested with a breathalyzer.

Treatment engagement. Primary individual counselors completed the Working Alliance Inventory–Short Form (WAI-S; Busseri & Tyler, 2003). The WAI-S is a 12-item, self-report questionnaire consisting designed to assess different components of the working alliance, including, how closely the patient and counselor agree on and are mutually engaged in the goals of treatment, how closely the patient and therapist agree on how to reach the treatment goals, and the degree of mutual trust, acceptance, and confidence. The composite score, which has a range of 7 to 84, is used as a global measurement of working alliance, with higher scores indicating stronger alliance.

Primary individual counselors also completed the Staff Rating Scale (SRS; Sacks & Levy, 1979). The SRS is a 5-item scale designed to assess the program participation and behavioral change of patients receiving residential care. Counselors rate the performance of participants in each of the following five areas: (a) Detail (Work Assignment), (b) Relationship to Peers, (c) Relationship to Staff, (d) Participation in Program, and (e) General Attitude. Scores range between 5 and 25, with higher scores indicating more appropriate participation in the program. The SRS has high temporal stability (i.e., .88) and has been shown other studies to predict successful treatment completion (Fals-Stewart & Lucente, 1994).

The Client Assessment Summary (CAS; Kressel, De Leon, Palij, & Rubin, 2000) is a 14-item self-report measure designed to measure patients' perceptions of progress along 14 domains of behavior, attitude, and cognitive change. All items are rated on a 5-point Likert scale. A total summary score can range from 14 to 70, with higher scores indicating higher levels of treatment engagement.

Treatment commitment. Length of stay (LOS) was a count of the number of days between formal admission and discharge into the program; this was documented in the medical chart. Whether or not the participant was classified as successfully graduating from the program was also noted in the medical chart.

Study intervention attendance, participation, and satisfaction. All CACR and CATT sessions were monitored by a research staff member, who recorded the number of sessions attended (out of 24 scheduled). Additionally, at the end of each attended session, the staff member rated, on a scale of 1 to 10, how engaged the patient was with the computer exercise, with "1" reflecting "*no engagement*" and "10" indicating "*full engagement*." The *Client Satisfaction Questionnaire* (CSQ-8; Larsen, Attkisson, Hargreaves, & Nguyen, 1979) is an 8-item measure designed to assess client satisfaction with services. Scores range from 0 to 32, with higher scores indicating greater satisfaction.

Statistical Methods

Primary group comparisons. Multilevel regression (MLR) models were used to examine the effect of treatment group (CACR or CATT) on the primary outcome measures for the intent-to-treat sample of all randomized participants. Scores generated from most of the measures were treated as continuous and thus the MLR models used a normal sampling model (i.e., the data had a normally distributed error structure). However, PDA and several of the ASI scales were significantly skewed and were thus natural log transformed. For these comparisons, modeling was conducted using MLwiN software (Rasbash, Charlton, Browne, Healy, & Cameron, 2009).

Mediation modeling. When operationalized, the model of how CACR may work consists of multiple mediators in a causal chain and will be analyzed using what is often referred to as distal mediation analysis. Procedures described by Fletcher (2006) and Holmbeck (1997) for testing distal mediation were used and the model to be tested is shown in Figure 1. Initially, a partially mediated structural model was tested, consisting of the primary direct effect (pathway g) and paths a, b, and c, with paths e and f constrained to zero. Second, the partially mediated model was compared to a fully mediated causal chain model (paths a,

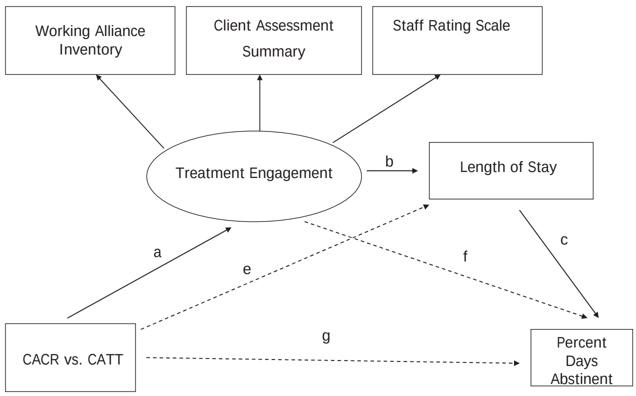

Figure 1. Causal chain distal mediation structural model. Paths "a," "b," and "c" represent the hypothesized causal chain fully meditational path; "g" represents primary direct effect. Paths "e" and "f" represent other direct effects.

b, c) with paths e, f, and g constrained to zero. Third, paths e and f were tested to determine if their inclusion improved model fit. Fourth, in the best fitting model, the hypothesized distal mediated effect (paths a, b, and c) was tested for significance using the multivariate delta method (Fletcher, 2006; Sobel, 1982). Mediation modeling was conducted using MPlus version 5.2 (Muthen & Muthen, 2007).

Handling missing data. As with nearly all longitudinal substance abuse treatment outcome studies, some participants did not provide data at all assessment points; 13 participants (8%) had at least one missing observation during one or more of the assessment periods that were scheduled during and 1 year after treatment. In total, 14% of all observations during treatment and during the post-treatment follow-up were missing. Multiple imputation (MI) methods as implemented in MLwiN were used (for a discussion, see Carpenter & Goldstein, 2004). Multiple data sets (i.e., 40) were generated, consistent with recent recommendations (Graham, Olchowski, & Gilreath, 2007). Analyses of the separate data sets were then combined, with final parameter estimates and standard errors obtained by combing the results using arithmetic rules outlined in Rubin (1987).

For the mediation models, likelihood ratio chi-square tests for the multiply imputed data sets were combined using an approach described by Meng and Rubin (1992) and implemented in MPlus. Along with chi-square tests to evaluate overall model fit, two other measures of fit we used to assess the models recommended by Hu and Bentler (1999): the comparative fit index (CFI) and the root mean square error of approximation (RMSEA).[1] CFI values of .95 or greater and RMSEA values of .06 or less indicate good model fit.

Results

Study Sample

Figure 2 shows the patient flow from screening through 12-month follow-up. A total of 199 individuals met program eligibility requirements and were admitted to the program. Of these, 176 expressed initial interest in participating in the study; 16 of these either declined to participate after gathering more information ($n = 6$) or left the program before signing informed consent and completing the baseline assessment ($n = 10$). Thus, 160 participants were randomized into the study. Table 1 presents the sociodemographic, background, and diagnostic information for the sample. Random assignment was effective; there were no significant differences between the participants in the two treatments on any of these characteristics (all *p*s $> .25$).

Intervention Attendance, Participation, and Satisfaction

The mean (*SD*) number of computer sessions attended by participants in the CACR condition, 17.4 (3.6), and the CATT condition, 18.0 (3.8), was not significantly different, $z = 1.04$, *ns*. Staff ratings of patients' active participation in the computerized exercises for the CACR condition, 9.0 (1.1), and the CATT condition, 8.7 (1.2), were high and not significantly different, $z = 1.64$, *ns*. Lastly, participants' satisfaction with the services provided as part of CACR, 25.1 (4.8), and CATT, 24.3 (5.0), were high and not significantly different, $z = 1.03$, *ns*. Thus, on average, participants in the two conditions attended the computer sessions, engaged in the exercises for the respective interventions, and reported reasonably high satisfaction with the interventions themselves.

Evaluations Conducted During Treatment

Cognitive functioning. NAB-SM *T* scores were not significantly different at baseline for those in the CACR condition ($M = 42.3$, $SD = 11.6$) and the CATT condition ($M = 43.5$, $SD = 10.9$), $z = 0.67$, *ns*. However, at the 9-week assessment, those in the CACR condition had significantly higher scores, ($M = 51.3$, $SD = 9.8$), than those in the CATT condition ($M = 47.7$, $SD = 9.5$), $z = 2.35$, $p < .05$. Thus, participation in CACR resulted in significantly greater improvement in cognitive functioning than participation in CATT.

Treatment engagement. As shown in Table 2, participants in CACR had significantly higher scores on all three measures of treatment engagement (all indicating higher levels) at the 9-week assessment.

Treatment commitment. Participants in the CACR condition stayed in residence for a greater number of days ($M = 129.2$, $SD = 45.2$) than those in the CATT condition ($M = 108.7$, $SD = 50.4$), $z = 2.67$, $p < .01$. Additionally, a significantly greater proportion of participants who received

[1] The CRI and RMSEA reported are mean values from the multiply imputed models that were run and provided by MPlus Version 5.2. However, the unweighted average of these fit indices from the imputed data sets is an ad hoc approach; at present, there is no universally accepted procedure or set of rules for combining these fit indices across multiply imputed data sets analyzed using structural equation modeling (see Enders, 2006).

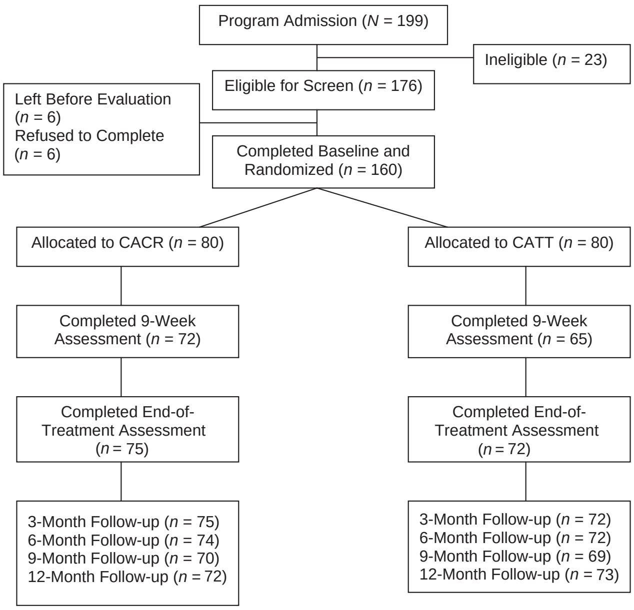

Figure 2. CONSORT diagram of participant flow through the protocol. CACR = computer-assisted cognitive rehabilitation; CATT = computer-assisted typing tutorial.

CACR graduated from the program successfully ($n = 44$, 55%) compared to those in CATT, ($n = 30$, 37.5%), $\chi^2(1, N = 160) = 4.25$, $p < .05$.

Treatment Outcome

For participants in the CACR and CATT conditions, mean (*SD*) ASI composite scores and PDA at baseline and at 12-month follow-up are located in Table 3. There were no significant differences between the conditions at baseline. However, at 12-month follow-up, compared to participants in CATT, those who received CACR had lower ASI Alcohol, Drug, Legal, and Family-Social composites and higher PDA[2].

Casual Chain Model

The partially mediated model was tested first (i.e., from Figure 1, inclusion of paths a, b, c, and g). In this model, all paths were significant (i.e., $p < .05$) except g; this model fit the data poorly, $\chi^2(21, N = 160) = 79.5$, $p < .001$, CFI = .88, RMSEA = .14. We then tested a fully mediated model (i.e., removal of path g from the partially mediated model); the χ^2 was significant, $\chi^2(20, N = 160) = 45.4$, $p < .01$, but other indicators revealed a good fit, CFI = .95, RMSEA = .06. Additionally, the likelihood ratio test indicated that the fully mediated model yielded a significantly better fit than the partially mediated model, $\Delta\chi^2(1, N = 160) = 34.1$, $p < .001$. Using modification indices, the addition of path e would significantly improve model fit. Once that path was added, all indicators revealed good model fit, $\chi^2(19, N = 160) = 29.1$, $p > .05$, CFI = .98, RMSEA = .02. This model fit the data better than the fully mediated model, $\Delta\chi^2(1, N = 160) = 16.3$, $p < .001$. Addition of path f did not improve fit. The final model is shown in Figure 3.[3] In this model, the hypothesized standardized indirect effect ($a \times b \times$ c) was significant, $\beta = -0.02$, $SE = .01$, $z = 2.69$, $p < .01$.

Cognitively Impaired Versus Unimpaired Patients

As shown in Table 1, roughly a third of participants in the two treatment conditions were classified as cognitively impaired, based on *T* scores from the NAB-SM. The comparative response of impaired versus unimpaired participants to the different treatments was not a focus of this study. However, in the analytic comparisons between CACR and CATT, impairment status was included as a factor in the models. There were significant main effects (*p*s $< .05$) of impairment status on many of the treatment response (impaired patients had shorter stays) and outcome variables (impaired patients had lower pretreatment and posttreatment PDA and higher pretreatment and posttreatment ASI scales–Drug, Alcohol, Family-Social). However, none of the treatment Condition X impairment status interaction terms was significant in any of the models.[4]

Discussion

The purpose of this study was to determine whether participation in cognitive rehabilitation, compared to an

[2] Among the measures reported, PDA was collected on multiple occasions. Of interest in this study was the aggregate PDA during the 12-month posttreatment period (starting at the end of treatment and culminating at the 12-month assessment interview; 5 assessments in total). Any one of the five assessments could have missing data (e.g., a participant may have missed his or her 6-month posttreatment interview, but attended all others, leaving 1 period with missing data). To obtain values for PDA, missing values at various interview points could be imputed, thereby allowing for the summary aggregate calculation for PDA across the assessments. Thus, missing assessment interviews were imputed using MI and, for each of the 40 data sets generated, an aggregate PDA was calculated and used in the multiply imputed mediation models.

As an alternative, we also counted PDA as missing if any assessment interview information (which would be needed to compute the aggregate PDA for the 12-month follow-up) was missing and then addressed the issue of missingness using full information maximum likelihood (FIML). The results from this approach were not substantively different than those reported here (and are available from the corresponding author upon request). We opted to use the MI approach because the lost of information by counting PDA as missing if any interview was missed (even if most of the information was available) was not justified. There are many approaches to handling data missingness in structural equation models, with FIML and MI usually recommended as methods for addressing this issue; both approaches have their adherents (see Allison, 2003; Olinski, Chen, & Harlow, 2003).

[3] For these models, it is important to note that the parameter estimates were combined for 40 multiply imputed data sets. As such, there is not a single correlation or covariance matrix. The matrices derived from the 40 data sets are available from the corresponding author upon request.

[4] The result of these exploratory analyses are available from the corresponding author upon request.

Table 2
Mean (SD) Scores on Treatment Engagement Measures

	CACR ($N = 80$)		CATT ($N = 80$)		
Measure	*M*	*SD*	*M*	*SD*	*z*
WAI-S	70.9	7.6	67.5	8.1	2.68**
SRS	20.6	4.8	18.0	4.3	3.29**
CAS	59.2	9.5	55.0	8.7	2.78**

Note. CACR = computer-assisted cognitive rehabilitation; CATT = computer-assisted typing tutorial; WAI-S = Working Alliance Inventory-Short Form (completed by primary counselor); SRS = Staff Rating Scale; CAS = Client Assessment Survey.
** $p < .001$.

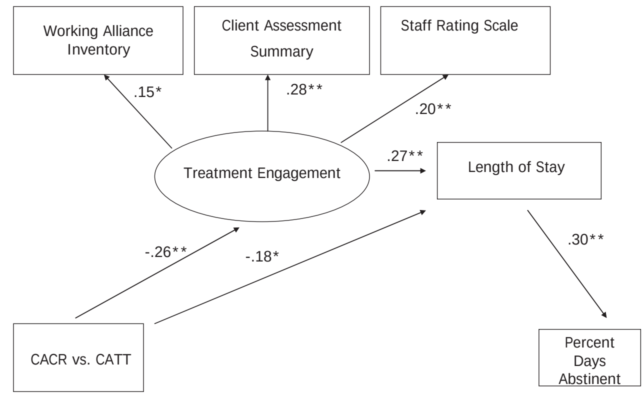

Figure 3. The final mediation model. Numbers are path coefficients for the indicated paths. * $p < .05$. ** $p < .01$.

equally intensive attention control treatment, would lead to better treatment response and outcomes for patients diagnosed with substance use disorders. The a priori hypotheses of the investigation were generally supported. In comparison to participation in an attention control treatment, CATT, participation in CACR resulted in better treatment engagement and treatment commitment. In addition, participants who received CACR had comparatively better posttreatment outcomes, not only in terms of substance use frequency reduction, but also along other indicators of addiction severity. The differential effect of the two interventions on substance use frequency during the 12-month posttreatment period was mediated by measures of treatment engagement and length of stay in residence. Overall, results do not appear to be because of intervention fidelity or satisfaction with the treatments; differences between the conditions on these dimensions were not significant.

Table 3
Mean (and SD) Addiction Severity Index (AS) Composite Scores and Percent Days Abstinent for Participants in Computer-Assisted Cognitive Rehabilitation (CACR) and Participants Who Received Computer-Assisted Typing Tutorial (CATT)

Scale and condition	Pretreatment	12-month follow-up
ASI Composite		
Alcohol		
CACR	0.29 (0.14)	0.11 (0.15)[a,b]
CATT	0.30 (0.13)	0.19 (0.11)[a]
Drug		
CACR	0.42 (0.12)	0.15 (0.09)[a,b]
CATT	0.39 (0.14)	0.25 (0.11)[a]
Employment		
CACR	0.78 (0.29)	0.41 (0.26)[a]
CATT	0.74 (0.32)	0.50 (0.29)[a]
Medical		
CACR	0.35 (0.39)	0.22 (0.25)
CATT	0.38 (0.42)	0.24 (0.38)
Psychiatric		
CACR	0.35 (0.19)	0.18 (0.22)[a]
CATT	0.32 (0.25)	0.22 (0.24)
Legal		
CACR	0.27 (0.25)	0.10 (0.18)[a,b]
CATT	0.25 (0.28)	0.18 (0.16)
Family-Social		
CACR	0.27 (0.24)	0.12 (0.20)[a,b]
CATT	0.26 (0.23)	0.21 (0.21)
Percent days abstinent		
CACR	28.3 (19.4)	71.4 (25.6)[a,b]
CATT	25.6 (20.2)	53.8 (28.1)[a]

Note. CACR = computer-assisted cognitive rehabilitation; CATT = computer-assisted typing tutorial. Percent days abstinent derived from the Timeline Followback Interview. There were no significant differences on any of measures at baseline (i.e,. all *p*s > .25).
[a] Significant difference between pretreatment and 12-month follow-up, using a Bonferroni-corrected alpha of $p < .007$. [b] Significant difference between CACR and CATT at 12-month follow-up using a Bonferroni-corrected alpha of $p < .007$.

The findings of the trial have important clinical implications. It has long been known that a significant proportion of patients with substance use disorders have measurable cognitive impairment and that the presence of these impairments may interfere with intervention efforts. Additionally, there is strong evidence that, in most cases, cognitive performance improves over time with extended abstinence. Investigators have hypothesized for many years that if the rate of cognitive improvement could be accelerated by exposing patients to environments that promote better cognitive functioning, this could result in better treatment response (e.g., Goldman, 1990). The results of the present study provide the strongest support of this hypothesis to date. Moreover, the results of the investigation show not only that experience-dependent improvement in cognitive performance has positive effects on outcomes, but also provides preliminary information on the mechanisms through which this effect evolves.

Indeed, if accounting for cognitive functioning among substance-abusing patients leads to comparatively stronger outcomes, this finding suggests other "neurocognitively informed" approaches that might also be effective. For example, interventions designed to make accommodations for and teach certain cognitive skills (e.g., problem-solving, memory) have shown promise for patients with SUDs (e.g., Czuchry & Dansereau, 2000a, 2000b, 2000b). Others have explored the use of medication (i.e., amlodipine) to improve cognitive performance among patients with SUDs to ascertain whether it has positive effects on outcomes (Turner, LaRowe, Horner, Herron, & Malcom, 2009).

It is plausible that the positive effects of CACR may improve response to various forms of psychosocial intervention for substance use, since it appears to improve cognitive performance (which is a necessary foundational element for virtually any kind of psychosocial intervention). Additionally, engagement in CACR or other forms of cognitive rehabilitation may serve to enhance response to targeted interventions that are often provided to patients with SUDs while in treatment (e.g., HIV risk reduction training, family-involved therapies). These hypotheses await future empirical evaluation.

The investigation had many important strengths, both in general and relative to previous cognitive rehabilitation studies with patients diagnosed with SUDs. The study recruited a comparatively large sample of participants, randomly assigned to equally intensive conditions, who comprehensively evaluated with psychometrically sound measures of cognitive functioning, indicators of treatment response, substance use, and psychosocial adjustment. Long-term posttreament functioning across multiple dimensions of functioning was also evaluated. The trial was sufficiently powered to allow for testing of a causal chain model that had been hypothesized, but not yet evaluated. The investigation represents the most comprehensive evaluation to date of cognitive rehabilitation as an intervention for substance abuse conducted to date.

Although the investigation represents a significant advance in terms of our understanding of the effects on cognitive rehabilitation with patients diagnosed with SUDs, there are several important limitations that should be highlighted. Although the cognitive rehabilitation exercises were designed to improve various circumscribed cognitive functions (e.g., problem-solving, memory, attention), only a broad measure of general cognitive functioning was used. The results of the NAB-SM revealed comparatively faster global improvement of cognitive functioning (after 9 weeks) for those who received CACR, suggesting that the intervention was working as intended, it is not possible from these findings to determine whether CACR was having differential effects on these cognitive skills (e.g., working memory, interference control, attention). If specific cognitive skills are affected differentially, there may be additional compensatory cognitive functions that are enabled to improve treatment response.

Relatedly, there are likely several other links in the causal chain model between substance-dependence, neurocognitive dysfunction, cognitive rehabilitation, and treatment outcome that are not represented or evaluated in this study. First, the implicit hypothesis in this study and others trying to amerliorate cognitive impairments among SUD patients is that doing so will facilitate patients' ability to learn new health promoting information, and execute new behavior change plans. However, whether patients in fact acquired new information and skills, gained skills at behavior plan execution, and, in turn, whether this new learning in fact, caused patients to engage more fully in treatment, was not examined in this study.

The second major part of the implicit causal chain that was not examined lies in the hypothesized underlying neuropathological or physiologic mechanisms. That SUDs are associated with cognitive impairments is well established; the mechanisms underlying these neuropathological alterations are not fully determined. Some have identified changes related cocaine dependence to be due to vascular infarcts (Kosten, 1998) and excitotoc cell death (Fleckenstein, Gibb, & Hanson, 2000). Others have focused on neurocognitive processes relating to prefrontal cortex activity (Bolla et al., 2003, 2005; Tanabe et al., 2007). The present study does not examine the role of these mechanisms, although these parts of the causal chain will be important for future research to attempt to elucidate. The role of neurocognitive processes, particularly prefrontal cortex activity, is indirectly supported by study findings that continue to link global cognitive functioning with treatment response and outcomes among substance-dependent patients. Follow-up studies using advances in neuroimaging to determine if activity in this region covaries with cognitive functioning, cognitive rehabilitation, and treatment outcome are needed to further elucidate these as potential underlying mechanisms.

The present study addressed several general methodological and design flaws of previous investigations in this overall programmatic line of research. Yet, it is nonetheless important to highlight certain limitations of this study in these areas as well. Participants were drawn from one long-term residential program. Although the program was very typical of other residential programs in the United States in terms of structure and content (e.g., Minnesota model philosophy), findings may not fully generalize to other settings and other kinds of treatments. Recruiting participants from long-term residential treatment has great advantages for studies the broadly examine cognition and cognitive functioning; the highly controlled environment reduces the likelihood of contamination of neuropsychological and other measures due to substance use. Indeed, in certain important respects, the present study and the other cognitive rehabilitation conducted in residential treatment settings can be viewed as "proof of concept" projects since the settings themselves provide so much control over many important confounding variables (e.g., other treatments received, relapse). Only a very small proportion of patients with SUDs in the United States receive treatment in long-term residential care settings.

Given the consistency of findings in these residential settings, however, it is time to examine the effects of cognitive rehabilitation on treatment response and outcome among patients with SUDs who are receiving treatment in more widely used settings, such as outpatient treatment programs, which is by far the most common milieu for substance abuse treatment, and to examine the effects of cognitive rehabilitation on patients with comorbidities, especially those for which cognitive rehabilitation intervention has show promise, such as traumatic brain injury (TBI) or posttraumatic stress disorder (PTSD). In light of their portability and ease of use, cognitive rehabilitation interventions may be particularly promising for military soldiers for whom SUDs, TBI, and PTSD are highly prevalent, may hold particular promise.

The use of cognitive rehabilitation to enhance the effects of primary interventions for substance use disorders is clearly supported. Future research needs to ascertain precise mechanisms by which these effects occur, as well as to determine whether these positive effects are observed with different forms of treatment, among different patient populations, and in more widely used therapeutic milieus. However, the results of the present trial hold great promise to become an important tool in the armamentarium for providers who are charged with treating patients with SUDs.

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