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Remember the future: working memory training decreases delay discounting among stimulant addicts

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Abstract

Background—Excessive discounting of future rewards has been observed in a variety of disorders and has been linked to both the valuation of the past, and memory of past events.

Methods—To explore the functionality of discounting and memory, we examined whether training working memory would result in less discounting of future rewards. In the present study, 27 adults in treatment for their stimulant use were randomly assigned to receive either working memory training or control training according to a yoked experimental design. Measures of delay discounting and several other cognitive behaviors were assessed pre- and post-training.

Results—Rates of discounting of delayed rewards were significantly reduced among those who received memory training but were unchanged among those who received control training; other cognitive assessments were not affected by memory training. Discount rates were positively correlated with memory training performance measures.

Conclusions—To our knowledge, this is the first study demonstrating that neurocognitive training on working memory decreases delay discounting. These results offer further evidence of a functional relationship between delay discounting and working memory.

Keywords

Stimulants; Addiction; Working Memory; Delay Discounting; Neuro-Cognitive Rehabilitation; Neuro-behavioral Decisions Systems Theory of Addiction

Introduction

One neurobehavioral process evident in a variety of disorders and/or suboptimal behaviors is a high level of delay discounting (1). Delay discounting refers to the decrease in value of a reward as a function of the delay to its receipt (2); an individual's rate of discounting can be measured by assessing preferences between a sooner, smaller reward or a later, larger one.

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Higher rates of discounting are associated with drug dependence (2), problem gambling (3), obesity (4,5), and human immunodeficiency virus (HIV)-risk behaviors (6,7). Given that delay discounting underlies a wide variety of disadvantageous behaviors it may function as a trans-disease process (8).

The correlation between rates of delay discounting and suboptimal behaviors has led, in part, to efforts to better understand discounting in terms of its relationship to other decision-making and neurocognitive processes. Consideration and valuation of the future has been shown to overlap with processes and brain regions associated with memory and/or valuation of the past (9,see 10, for a review). For example, discounting of past and future rewards have been found to be qualitatively and quantitatively comparable (11–13) by conforming to the same signature hyperbolic function and magnitude effect, and bilateral damage to the hippocampus impairs the ability to remember the past and to imagine future personal experiences (14). More directly, recent demonstrations indicate significant correlations between measures of working memory and delay discounting (15,16). Thus, if consideration of and valuation of the past and future are linked (17,18), then it might be possible to decrease an individual's discounting of future events by increasing his/her ability to remember past events.

In the present study, we employ neurocognitive rehabilitation approaches, proven to be effective with individuals with schizophrenia (for reviews see 19,20), to examine the effects of working memory training on measures of delay discounting, working memory, and related assessments in individuals in treatment for psychomotor stimulants (e.g., cocaine and methamphetamine). Frequent or heavy users of stimulants have been shown to exhibit neurocognitive deficits, including deficiencies in working memory (21,22) and high rates of delay discounting (23,24).

In this study, participants receiving treatment for their stimulant use received either experimental or control memory training. Experimental (Active) Training consisted of working memory tasks with monetary reinforcement for performance. Control Training consisted of presenting the same working memory tasks and cueing the correct response. Reinforcement for each participant in the Control Group was yoked to performance of a participant in the Active Group; that is, yoking ensures that the amount of reinforcement obtained by each experimental group participant during each session is also obtained by each participant in the control group. Pre- and post-training assessments on a variety of decision-making and cognitive functions quantified the effects of training and determine whether the effects were selective or more general.

Methods and Materials

Participants

Twenty-seven (20 male, 7 female, mean age = 38.6 years) participants being treated for stimulant use at a substance-abuse treatment facility enrolled and completed all assessments. Stimulant Abuse/Dependence diagnosis was determined by clinical staff at the treatment facility using criteria established by the Diagnostic and Statistical Manual of Mental Disorders IV-TR (DSM, 25) and documented to be consistent with the findings from aspects of Addiction Severity Index – 5th Edition (ASI) administered to all individuals in the facility as a component of intake. All participants met the criteria for stimulant dependence, except two participants in the Active Group and three in the Control Group who met criteria at minimum for stimulant abuse, but dependence could not be determined. Participants were free from unmanaged symptoms of DSM-IV Axis I and II disorders and had no history of major brain insult. Additional participant characteristics can be viewed in Table 1.

Materials

Pre- and Post-training Assessments—Seven assessments were collected in sessions that occurred prior to and following completion of the training sessions. Participants were compensated $20 and $10 for the pre- and post-training sessions, respectively.

1. Frontal Systems Behavior Scale (FrSBe; 26). On this 46-item measure participants rate themselves on a 5-point scale and assesses behavioral sequela related to frontal lobe damage; it includes three behavioral syndromes—apathy, disinhibition, and executive dysfunction.
2. Letter Number Sequencing (LNS; 27). In this working memory assessment, a mixed combination of letters and numbers is presented to participants who must put them in sequential order, consisting of numbers first (ascending) followed by letters (alphabetical). The letter-number string presentation increases in difficulty (number of items) until the participant is no longer able to correctly sequence three strings of equivalent difficulty.
3. Balloon Analog Risk Task (BART; 28). For each trial of the computerized BART, an uninflated balloon appears on the monitor. Five cents (hypothetical) are earned and collected in a temporary reserve by inflating the balloon (via one unit per mouse click). This sum can be emptied into a permanent bank that cannot be lost. However, if the balloon continues to be inflated (adding money to the temporary reserve) and the balloon bursts, the amount in the temporary reserve is lost.
4. Go/No-Go Task (29). In this computerized procedure, four of eight 2-digit numbers are arbitrarily designated positive stimuli (S+) and four other 2-digit numbers are designated negative stimuli (S−). The participants' task is to learn by trial and error to respond (within 2 seconds) to S+ and not to respond to S−.
5. Phone Message Task. Located within the Memory II program of the PssCogRehab (PSSCogReHab, Psychological Software Services Inc.), this program assesses an individual's episodic memory by visually and aurally presenting a very detailed phone message. After a brief study period, participants answer a series of multiple-choice questions regarding details in the message.
6. The Hopkins Verbal Learning Test – Revised (HVLT-R; 30). This standardized assessment of verbal learning and memory requires memorization of a list of words aurally presented. Following a delay, participants are then asked to recall/recognize as many words as possible. The word lists differed between the pre- and post-training assessments.
7. Delay Discounting (2). Delay discounting was assessed using a computerized, binary choice procedure. In each trial, participants chose between an immediate, smaller and a later, larger amount of money. The dollar amount of the immediate outcome was adjusted from trial to trial according to a decreasing-adjustment algorithm while the delayed outcome remained constant, until the participant's response indicated indifference between the sooner, smaller reward and the later, larger reward. This procedure was employed to determine indifference points for each of three temporal discounting conditions: real $100, hypothetical $100 and $1000. The larger later reward was available for the real $100 task at 4 delays (1 day, 1 week, 1 month, and 6 months) and for hypothetical monetary amounts at 7 delays (1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 25 years). One of the choice trials from the real $100 condition was selected randomly at the conclusion of the session, and the participant received the outcome s/he picked for that trial.

Training Program—Four commercially available memory-training programs (PSSCogReHab, Psychological Software Services Inc.), modified to permit detailed measurement for the yoking design, were utilized during the training sessions. These were as follows:

1. Sequence Recall of Digits–Auditory (SRD-A): Participants were presented a series of numbers aurally and required to memorize the numbers in the order in which they were presented. The program began with a sequence of three digits, increasing by one digit upon a correct response, up to a maximum of 10 digits. An incorrect response resulted in a different sequence of the same number of digits. Five missed sequences resulted in the end of the program.
2. Sequenced Recall Reversed Digits–Auditory (SRRD-A): This program is identical to the SRD-A, with the exception that participants were required to recall the digits in the reverse order of presentation.
3. Sequenced Recall of Words–Visual (SRW-V): Participants were shown a list of four-letter words on a computer screen. After a brief study period, the participant was instructed to find the presented words in the correct sequence from a list of 16 words. The program began with three words, increasing by one word upon a correct response, up to a maximum of 11 words. An incorrect response resulted in a new list of the same number of words. Five missed sequences terminated the program.
4. Verbal Memory–Categorizing (VM-C): Participants were presented with 20 words falling into 4 categories (e.g., colors, vegetables). Participants were instructed to place each word into its correct category and then choose the original words from a list of 180.

Procedures

All participants completed one pre-training session, 4–15 training sessions, and one post-training session. The range of time lapsed between pre- and post-training sessions was 9–44 days, with a mean of 25 days. Participants were assigned into either the Active Training (14 participants) or Control Training (13 participants) conditions at the conclusion of the pre-training session according to our yoked design. Specifically, the first participant was assigned to the Active Training condition. Each subsequent participant was evaluated to ascertain if s/he met the matching criteria (gender and memory (LNS) score) of any participant in the Active Training condition. If a given participant met the matching criteria s/he was assigned to the Control Training condition. If the participant did not match any of the existing Active Training participants, s/he was assigned to the Active Training condition until we had accrued 14 participants in the Active Training condition.

Active Training—In each training session, participants completed each of the four memory training programs twice. The number of training sessions was determined by each participant's progress in the training programs; three consecutive sessions without an increase in performance on any two programs resulted in the conclusion of training, with a minimum of four and a maximum of 15 sessions. Participants were compensated $10 for attending each session and an additional $10 per session and for study completion. Participants were also compensated according to increasing schedules for performance. These schedules varied across training modules due to variations in performance thresholds and scoring, with a minimum of $0.00 and a maximum of $30.85 per session.

Control Training—The Control Training program was identical to the Active Training program in all essential features (e.g., stimulus, response, number of trials, progression, and feedback) with two exceptions. First, the Control Training program identified the correct

answers to the participants, so they did not need to engage working memory to obtain correct responses. Second, progression through modules and associated compensation for each Control Training participant was yoked to an individual in the Active Training Group.

Statistical Methods

Delay discounting rates were calculated using the exponential-power discounting function

$$v_d = e^{-k\sqrt{d}}, \quad \text{Eq. 1}$$

where v_d is the value of the sooner amount (reported as a proportion of the delayed amount), d is the delay, and k is the index of discounting. This model of discounting (see 31) provided a better fit (i.e., had a lower error sum of squares) of the delay discounting data in this study compared to Mazur's hyperbolic model in 73% (118 of 162) of all data sets. Due to positively skewed distributions of discounting coefficients, natural logarithm–transformed k-values were estimated and employed in the analyses of discounting.

Each pre- and post-training assessment was analyzed in a linear mixed model, with Treatment, Time, Subscale (for FrSBe, HVLT-R, and delay discounting), and all interactions as fixed effects and participant pair as a random effect. Since the Treatment–Time (pre to post) interaction is the effect of interest, we report these results and corresponding η_G^2 effect sizes. Composite performance measures of the training session for the Active Training participants were calculated by adding scores from the SRD-A, SRRD-A, SRW-V, and one-third of the VM-C(to equate its weight to the other three scales).

Results

Active and Control Training Groups did not statistically differ on any demographic variables. Because of a marginal non-significant difference between the mean ages of the two groups (35.7 for Active vs. 41.6 for Control, $t_{25} = 1.89$, $p = 0.070$), age was included as a covariate in subsequent analyses. When it was found not to impact inferences, age as a covariate was dropped from the final models.

Effects of Training

No differential effect of training condition was observed for any of the following pre- to post-training assessments: FrSBe ($F_{1,275} = 0.41$, $p = 0.524$, η_G^2=0.001), LNS ($F_{1,25} = 0.13$, $p = 0.721$, η_G^2=0.005), BART ($F_{1,25} = 0.43$, $p = 0.520$, η_G^2=0.017), Go/No-Go Task, ($F_{1,25} = 0.01$, $p = 0.921$, η_G^2=0.000), Phone Message Task ($F_{1,25} = 0.50$, $p = 0.486$, η_G^2=0.020), and HVLT-R ($F_{1,125} = 1.84$, $p = 0.178$, η_G^2=0.014).

In contrast, an effect of training was observed with measures of delay discounting (see Table 2). The treatment-by-time interaction was significant ($F_{1,122} = 9.01$, $p = 0.003$, η_G^2=0.069; Figure 1), with no evidence that this effect differed across the three discounting conditions tested ($F_{2,126} = 0.08$, $p = 0.925$). Those undergoing Active Training significantly decreased their discounting rate k by 50% on average. Though not significant, the Control Group participants *increased* their rate by 50%.

A nonparametric approach was also used to evaluate whether memory training affected a decrease in discounting. Specifically, the number of discounting tasks on which each participant showed a decrease at the post treatment assessment was counted (three being the maximum possible). The two treatments were compared on their distributions of these counts with a (one-sided) Wilcoxon-Mann-Whitney test. The Active Group exhibited decreases in more of the three discounting tasks examined ($\chi^2_{(df=1)} = 5.54$, $p = .013$). The

distributions of the counts of participants' decreases in delay discounting are given in Table 3. Figure 2 shows the change in discounting rate from pre- to post-training in the $100 hypothetical monetary discounting procedure for each individual. In this measure, 9 participants in the Active Group showed a decrease (indicated by positive change values), while 2 participants in the Control Group showed a decrease.

Relationship Between Memory and Discounting

Pre- and post-training assessments were correlated with composite working memory by obtaining Spearman's correlation coefficients between pre-training discount assessments and the composite working memory score from the first training session and between the post-training discount assessments and the composite working memory score from the last training session. These analyses revealed significant correlations between delay discounting and working memory performance (Table 2). Overall, these data illustrate post-training rates of delay discounting were significantly associated with the composite working memory performance scores from the last session in the Active Training Group. Moreover, the number of training sessions was significantly negatively correlated with post-training discounting rate only in the Active Training Group ($r = -.54$, $p = .048$).

Discussion

This study suggests that working memory training among stimulant-dependent individuals results in a decrease in discounting of delayed rewards consistent with previous reports of a relationship between working memory and delay discounting. This effect of training working memory was selective and did not affect any other pre- and post-training measures. Moreover, the absence of any significant effects in the Control Group indicates that these effects are not related to attention, exposure to the stimuli associated with working memory training, or the reinforcers delivered. Instead, the results support that the change in discounting resulted from reinforced working memory training. There are four comments that we would like to make regarding these findings.

First, these results, if replicable, support a new strategy or intervention by which to decrease the discounting of delayed rewards. Several studies have demonstrated that discounting measures can be manipulated. Many of these studies have been focused on either framing effects (e.g., the hidden-zero effect; 32) or situational changes (e.g., reinforcer deprivation level; 33) to produce change. To our knowledge, the present study is the first to demonstrate that neurocognitive training of working memory can decrease delay discounting. This result is consistent with data from studies demonstrating a correlation between working memory performance and delay discounting (21,22). The findings also corroborate studies supporting a strong relationship between valuation of the past and valuation of the future (11–13) and other studies using functional magnetic imaging indicating an overlap of brain regions (such as the dorsolateral prefrontal cortex) that are activated during working memory and delay discounting tasks (cf. 34,35,36).

Second, these findings support the competing neurobehavioral decision systems hypothesis of addiction (11). According to this neuroeconomic approach, decisions are made based on two decision systems. One, referred to as the impulsive decision system, is embodied in the limbic and paralimbic brain regions and is associated with the acquisition of more immediate reinforcers. The other, referred to as the executive system, is embodied in the prefrontal cortex and is associated with planning and deferred outcome. According to this hypothesis, addiction results from a hyperactive impulsive system and a hypoactive executive decision system. Interestingly, McClure et al. (35) showed that delay discounting may provide a summary measure of the relative control of these two systems. Specifically, he and his colleagues measured brain activation during choices between immediate and

delayed rewards and found greater relative activation of the impulsive system when the immediate option was chosen and greater relative activation of the executive system when the latter option was chosen. By providing a summary of the relative preference for immediate or delayed options, delay discounting rates may serve as a summary measure of the relative control by these two brain systems. Based on that view, greater discounting among addicts is consistent with the notion of a hyperactive impulsive system and a hypoactive executive system specified by the competing neurobehavioral decision systems hypothesis. Moreover, our observed decrease in the rate of discounting following working memory training is consistent with an increase in relative activation of the executive system.

Third, the results of this study suggest several lines of future inquiry. For example, an important question is the durability of the effect examined here. Does this change in discounting persist or dissipate? If the effect decays over time, can booster working memory training sessions continue the effect? Pursuant to this, is there a ceiling on the effects of training? Another set of questions concern whether the training effect would be observed in other diagnostic groups with greater rates of discounting than controls. Such a pervasive effect would provide supporting evidence that excessive delay discounting is a trans-disease process. However, given that previous studies among smokers have shown that individuals who discount less exhibit better treatment outcomes or are less likely to relapse (37–40), perhaps the most important question is whether a decrease in the rate of discounting also results in improvements in treatment outcomes.

Finally, this study supports the viability of neurocognitive rehabilitation to improve at least one aspect of executive function among addicts. Such approaches have been shown to be effective for brain injury (depending upon the magnitude of the injury) and for schizophrenia (18,19). A prior effort to improve executive function in addiction have resulted in limited improvement (41). The present study differs from previous approaches in that only a single executive function (i.e., working memory) was trained while assessments examining the effects of that training included a variety of other decision/executive function tasks. Perhaps isolating executive functions for training would reveal other interesting effects among other executive functions. Importantly, these changes in executive function are consistent with the notion of neuroplasticity and suggest that at least some of the neurocognitive deficits related to addiction might be reversible.

We note that although memory performance during training was significantly correlated with discounting, the pre- and post-training measures of memory were not different. This is likely due to a lack of sensitivity of the LNS, whose scoring algorithm may not be able to detect less than large changes in performance. Alternative explanations are that working memory training does not improve working memory performance, that LNS and training programs are sufficiently different so that training on one will not influence performance on the other even if working memory is improved, or that there was insufficient duration to document working memory improvement. In particular, the potential for insufficient working memory training may be related to the variability in training duration across participants. If the latter was the case, then providing sufficient training may also change the degree of selectivity observed here. However, clarification of these different outcomes will await further examination with alternative measures of working memory such as the O-Span Working Memory measure which has been shown to be more sensitive to interventions (e.g., 42). However, we note again that working memory measures of performance in the training modules were appropriately correlated with delay discounting scores.

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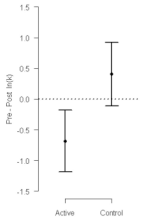

Figure 1.
Differences in discounting (and 95% CIs) from pre- to post-trial for Active and Control Groups.

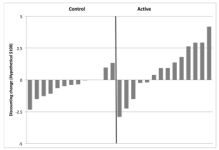

Figure 2.
Change in discounting ln(*k*) for individual participants in the Active and Control Groups, calculated as pre-training minus post-training. Positive values indicate a decrease in discounting.

Table 1

Participant Characteristics

	Control (N=13)	Active (N=14)	Test statistic and p-value
Years of education [Mean (SD)]	12.0 (1.7)	12.4 (1.7)	$t_{25} = 0.64$; $p = 0.528$
Quick Test IQ [Mean (SD)]	37.1 (5.1)	37.4 (3.0)	$t_{25} = 0.17$; $p = 0.862$
Years using Stimulants [Median (IQR)]*	14.5 (11.5, 20.5)	12 (3, 13)	$\chi^2_{(1)} = 3.24$; $p = 0.085$
Primary Stimulant of Abuse [%] **			
Cocaine only	77	71	
Methamphetamine only	15	22	$\chi^2_{(2)} = 0.16$; $p = 0.922$
Both cocaine and methamphetamine	8	7	
Has history of non-stimulant use [%]	77	79	$\chi^2_{(1)} = 0.01$; $p = 0.918$

* Failed to collect data for two participants, one from each group.

** A chi-square test of independence with degrees of freedom (df)=2

Table 2

Spearman Correlation Coefficients Between Discount Rates and Memory Training Scores in Active Training Group

	First Training Session (*p* value)	Last Training Session (*p* value)
Pre-Training Discounting		
Hyp $100	−0.65 (0.01)	−0.58 (0.03)
Hyp $1000	−0.45 (0.11)	−0.42 (0.14)
Real $100	−0.38 (0.20)	−0.29 (0.32)
Post-Training Discounting		
Hyp $100	−0.44 (0.11)	−0.52 (0.06)
Hyp $1000	−0.54 (0.05)	−0.61 (0.02)
Real $100	−0.35 (0.22)	−0.37 (0.19)

Hyp = Hypothetical

Table 3

Participants in Control and Active Groups Showing Decrease in Delay Discounting

	# Discounting Procedures With Decreased *k*			
Count (row %)	**0**	**1**	**2**	**3**
Control	7 (54)	4(31)	1 (7.5)	1 (7.5)
Active	3 (21.5)	2 (14)	3 (21.5)	6 (43)