148 (2023) 209007

Contents lists available at ScienceDirect

Journal of Substance Use and Addiction Treatment

journal homepage: www.journals.elsevier.com/journal-of-substance-use-and-addiction-treatment

Examining neurobehavioral differences that support success in recovery from alcohol and other substance use disorders☆

Medha K. Satyal [a,1], Julia C. Basso [a,b,c,1], Hannah Wilding [c], Liqa N. Athamneh [b], Warren K. Bickel [b,*]

[a] Department of Human Nutrition, Foods, and Exercise, Virginia Tech, VA, USA
[b] Fralin Biomedical Research Institute at VTC, VA, USA
[c] School of Neuroscience, Virginia Tech, VA, USA

ARTICLE INFO

Keywords:
Drugs
Alcohol
Abstinence
Health behaviors
Executive functioning

ABSTRACT

Objective: Substance use disorders (SUDs) are brain disorders associated with impairments resulting from the recurrent use of alcohol, drugs, or both. Though recovery is possible, SUDs are chronic, relapsing-remitting disorders, with estimates of SUD relapse at 40–60%. Currently, we know little about the mechanisms underlying successful recovery processes and whether substance-specific mechanisms exist. The current study sought to examine delay discounting (a measure of future valuation), executive skills, abstinence duration, and health behaviors in a population of individuals in recovery from alcohol, stimulants, opioids, and other substances.

Methods: In this observational study, we utilized a cohort of individuals (n = 238) from the International Quit and Recovery Registry, an online registry for those in recovery from SUDs around the world. We assessed delay discounting through a neurobehavioral task, and assessed abstinence duration, executive skills, and engagement in positive health behaviors through self-report measures.

Results: We found that delay discounting, executive skills, and engagement in positive health behaviors were similar among individuals in recovery from different substances. Abstinence duration was associated with delay discounting and engagement in health behaviors. Additionally, executive skills and engagement in health behaviors were positively associated.

Conclusion: These findings suggest that common behavioral mechanisms support recovery from misuse of various substances. As both delay discounting and executive skills are dependent upon executive brain centers, such as the prefrontal cortex, strategies that target executive functioning, such as episodic future thinking, meditation, or exercise, may be efficient strategies for optimizing recovery from SUDs.

1. Introduction

Substance use disorders (SUDs) are brain disorders characterized by impairments caused by the recurrent use of alcohol, drugs, or both. This impairment may be manifested in areas such as physical/mental health, educational/work responsibilities, or relationships with friends, families, or other social counterparts. SUDs afflict approximately 7.4% of individuals living in the United States each year (Merikangas & McClair, 2012; Substance Abuse and Mental Health Services Administration, 2019). SUDs are treatable and can be managed through medical, psychological, and other behavioral treatments. However, SUDs are chronic, relapsing-remitting disorders, and therefore the return to substances is common, with estimates of SUD relapse at 40–60%, similar to relapse rates of other chronic illnesses (McLellan et al., 2000).

Historically, definitions of recovery focused on the concept of abstinence. However, newer definitions focus on a multitude of factors that promote successful recovery (Witkiewitz et al., 2020). Success in recovery could mean engaging in education, obtaining gainful employment, acquiring new hobbies, healing relationships with family, friends, or co-workers, or making new friendships altogether (Neale et al.,

☆ Funding: This work was supported by the Fralin Biomedical Research Institute at Virginia Tech Carilion and NIH/NIAAA [grant number R01AA027381]. This work was also supported by NIH/NCATS [grant number UL1TR003015/KL2TR003016].

* Corresponding author at: Fralin Biomedical Research Institute at VTC, 2 Riverside Circle, Roanoke, VA 24016, USA.
E-mail address: wkbickel@vtc.vt.edu (W.K. Bickel).

[1] Medha K. Satyal and Julia C. Basso are co-first authors.

https://doi.org/10.1016/j.josat.2023.209007
Received 24 June 2022; Received in revised form 30 January 2023; Accepted 5 March 2023
Available online 20 March 2023

2014). Importantly, research has identified that, "recovery goes well beyond abstinence; it is experienced as a bountiful 'new life', an ongoing process of growth, self-change and of reclaiming the self" (Laudet, 2007). That is, new definitions focus on the concept of recovery as an ongoing, dynamic process of behavioral change resulting in improvements in biopsychosocial functioning and quality of life (Witkiewitz et al., 2020). Engagement in health behaviors is one important aspect of recovery. These behaviors include eating well, participating in an exercise routine, engaging in preventative health care, and getting enough sleep. However, the neurobehavioral mechanisms supporting engagement in health behaviors in individuals in recovery from SUDs are unknown. Here, we use the term neurobehavior/al to describe behaviors that are known to be dependent on distinct regions of the brain (from studies that have utilized neuroimaging techniques such as functional magnetic resonance imaging); that is, tasks such as executive function that are known to rely on the prefrontal cortex.

The Competing Neurobehavioral Decision Systems (CNDS) theory proposes that the reward-driven impulsive system and the regulatory executive system work in balance to promote healthy decision-making and engagement in positive behaviors (Bickel et al., 2007, 2018). The executive system is governed by frontal cortical brain regions (e.g., dorsolateral prefrontal cortex, anterior cingulate cortex), while the impulsive system is governed by limbic and paralimbic regions (e.g., amygdala, insula, striatum). CNDS balance can be assessed behaviorally via neurocognitive tasks of delay discounting and executive functions or skills. Delay discounting is a behavioral indicator of future valuation and assesses the balance between the impulsive and executive systems. Delay discounting is a behavioral mechanism underlying a range of health behaviors, most notably SUDs (Bickel et al., 2012, 2019; Bickel, Koffarnus, et al., 2014; García-Rodríguez et al., 2013; Perry et al., 2005; Phung et al., 2019). Additionally, previous research has suggested that individuals with SUDs display deficits in a range of executive functions, including inhibition, attention, and working memory, as a consequence of substance use disorder (Fernández-Serrano et al., 2010). Deficits in executive functioning may also be a risk factor for the onset of behaviors such as binge drinking and polysubstance use (Gustavson et al., 2017; Peeters et al., 2015). A shift in CNDS activity toward increased executive functions and future valuation may be critical to successful recovery.

The findings to date regarding executive and impulsive functions during recovery from SUDs have been mixed, with some studies suggesting that individuals in recovery from chronic substance use may experience persistent impairments in these domains (Ellis et al., 2016), while others suggest that these deficits improve with abstinence (Pope et al., 2002). Further, though polysubstance use is associated with impaired cognitive functioning compared to single substance use (e.g., alcohol use disorder) (Schmidt et al., 2017), less work has examined differences in the recovery processes of distinct SUDs. Various substances, including alcohol, stimulants, and opioids, have different biochemical, pharmacokinetic, toxicity, psychopharmacological, and behavioral profiles, therefore affecting users in distinctly different ways (e.g., differences in tolerance and withdrawal) (Shmulewitz et al., 2015). Additionally, patients with multiple SUDs, compared to single SUDs, demonstrate differences including a more persistent pattern and course of use (McCabe et al., 2017). Yet despite these differences, diagnostic and treatment guidelines are largely universal across substances. Distinguishing behavioral and other differences between SUDs is crucial to investigating the differential recovery processes of unique SUDs, and thereby providing substance-specific prevention and intervention to encourage sustained recovery (Shmulewitz et al., 2015).

Therefore, we sought to examine the neurobehavioral determinants of success in recovery by exploring the relationship among delay discounting, executive functions, health behaviors, and abstinence duration in a population of individuals in recovery from several different types of SUDs (including alcohol, stimulants, and opioids). Based on the concept that current diagnostic and treatment guidelines are consistent across substances, we hypothesized that delay discounting, executive functions, and health behaviors would be similar across substances but that these factors would be significantly associated with abstinence duration, suggesting that they support success in recovery across each category of SUD.

2. Methods

The study recruited participants from the International Quit and Recovery Registry (IQRR; https://quitandrecovery.org), an online community and registry of adults (≥18 years old) who self-report being in recovery from substance misuse and/or behavioral addictions (e.g., gambling, excessive video game playing). To register as a member of the IQRR, individuals provide contact information and complete an initial assessment, which contains questions about demographics and personal history of substance misuse and behavioral addictions. After registration, IQRR members gain access to the benefits of the registry and can complete any available research assessments. Participation in assessments is voluntary, and membership is not contingent upon the number of assessments that an individual completes. Participants are compensated for each assessment completed. Assessments were programmed and presented in LimeSurvey. In addition to providing research assessments to help members learn more about their trends and trajectories in recovery, the IQRR provides a community of support for members as well as resources aimed at promoting successful recovery.

The Institutional Review Board at Virginia Polytechnic Institute and State University approved the current investigation. All participants provided an online approved consent prior to beginning any study procedures.

2.1. Study measures

Demographics: The study collected demographic data in the IQRR initial assessment, which included gender, race, ethnicity, year of birth, level of education, and household income. We calculated age by subtracting the year of birth from the year in which the assessment was completed. To determine the primary addiction of each participant, we used a standard IQRR multiple-choice question in the initial assessment, "What was your primary addiction?" with the options: a) tranquilizers/depressants; b) prescription pain relievers; c) nicotine; d) cannabis products; e) cocaine; f) stimulants; g) opioids; h) alcohol; i) overeating; j) gambling; k) viewing pornography; l) shopping; or m) other. Examples were provided for each addiction (e.g., "opioids (heroin, opium, morphine, methadone)"). The study categorized individuals with alcohol use disorder as those participants who responded "alcohol"; stimulant use disorder for those participants who responded "stimulants" or "cocaine"; opioid use disorder for those participants who responded "opioids"; all other substances were categorized as other SUD. We use the term "substance misuse" in reference to this population, as we did not obtain information required to diagnose a DSM-V SUD.

Abstinence duration: The quit date of the participant's primary substance was collected in the IQRR initial assessment. The current assessment asked participants whether they have engaged in their primary substance since they joined the IQRR. The study calculated abstinence duration for those who answered "No" by subtracting the self-reported quit date collected at the initial assessment from the date on which the current assessment was completed. Those who answered "Yes" and indicated engagement in their primary substance since they joined the IQRR were subsequently asked if their substance use was ongoing (Yes/No). Participants who indicated ongoing use were considered to have 0 days of abstinence. Those who indicated no ongoing substance use were asked to report an updated quit date and the study calculated the abstinence duration by subtracting the updated quit date from the date on which the assessment was completed. Abstinence duration in days is used in all analyses.

Delay Discounting: The study used the five-trial adjusting delay discounting task (Koffarnus & Bickel, 2014) to assess future valuation.

Participants are first asked if they would rather receive $1000 in 3 weeks or $500 now. The delay of the larger reward in the subsequent trial increases or decreases based on the answer to the previous question. This process of adjusting delays repeats for a total of five trials. In delay discounting, the ED_{50}, or the delay expected to reduce the value of the larger reward by 50%, is known as the indifference point (Mazur, 1987). The inverse of the ED_{50} was calculated to provide an estimate of the discount rate (k). The natural log of k was used in all analyses. Though test-retest reliability of this task has not been assessed, discount rates for the five-trial adjusting delay discounting task are similar and correlate to discount rates from the adjusting amount task, and each of the four effects related to delay discounting (i.e., amount effect; past versus future reinforcers; consumable versus generalized reinforcers; zero amounts explicitly described) have been shown to be replicated with this task (Koffarnus & Bickel, 2014).

Executive functions: The study assessed executive functions using the Executive Skills Questionnaire, a 36-item self-report questionnaire used to assess executive skills. The questionnaire assesses 12 executive skills including response inhibition, working memory, emotional control, sustained attention, task initiation, planning/prioritization, organization, time management, goal-directed persistence, flexibility, metacognition, and stress tolerance (Dawson & Guare, 2010, 2012, 2018; Strait et al., 2020). Each item is scored on a range from 1 (*strongly disagree*) to 7 (*strongly agree*), with "1" indicating lower executive functioning and "7" indicating higher executive functioning. Items are summed for a total score ranging between 36 and 252, with higher scores indicating stronger executive functioning. All analyses used the total score. Though the original version of the Executive Skills Questionnaire that we utilized does not have psychometric properties available, a more recent revised version with 25 items found that the test has excellent internal consistency (alpha = 0.91), adequate test-retest reliability (0.70), moderate correlations with other executive function (0.56–0.74) and psychological symptom scales (0.38–0.55), and is significantly correlated with academic engagement (−0.40) (Strait et al., 2020).

Health behaviors: The study assessed health behaviors using the Health and Finance Related Behaviors Questionnaire, a 39 item self-report measure used to assess participants' level of engagement in health-related and finance-related behaviors (Supplementary Document 1). This questionnaire was designed in laboratory. Items were created based on health behaviors as assessed in previous work (Daugherty & Brase, 2010; DeHart et al., 2020; Snider et al., 2018). The questionnaire assesses 6 domains of health- and finance-related behaviors: addictive behaviors, preventative or health-related behaviors, driving behaviors, environmental behaviors, and financial behaviors. Each item was scored on a range from 1 (*never*) to 5 (*almost always*), with items reflecting poor health behaviors reverse scored. Items are summed for a total score ranging from 39 to 195, with a higher score indicating a higher level of engagement in positive health- and finance-related decisions.

2.2. Data cleaning

A total of 271 IQRR members submitted the current assessment. Individuals indicating a primary addiction that was not substance related (n = 11) were excluded from the analysis due to the unique set of complications that SUDs present compared to other behavioral addictions, such as the effects of addictive substances on the functioning of both the brain and body (including effects on discounting rates) (Bickel, Johnson, et al., 2014). Non-substance-related primary addictions included binge eating or other eating disorders (n = 1), gambling (n = 2), excessive viewing of pornography (n = 4), overeating (n = 2), excessive video gaming (n = 1), and other (i.e., self-injury) (n = 1). Given the need for information about abstinence duration provided by the IQRR initial assessment as described above, individuals who had not completed the IQRR initial assessment (n = 6) or who reported a quit date that was after the date they completed the questionnaire (n = 2) were excluded from the analysis. Additionally, the study excluded participants who did not complete the delay discounting task (n = 15) from the analysis, as delay discounting was a primary variable of interest. Based on these criteria, a total of 33 (~12%) participants were excluded from the analysis, including 1 participant who was excluded on the basis of more than one criterion. Thus, the final sample consisted of 238 participants (Fig. 1).

2.3. Statistics

The study conducted chi-square tests of independence to compare categorical demographic variables (i.e., gender, race, ethnicity, education, income) among substance groups. We conducted one-way analysis of variance for between groups comparisons of age and abstinence duration. We utilized analysis of covariance to compare delay discounting, executive skills, and engagement in health behaviors among groups controlling for significant demographic variables. Relationships among abstinence duration, delay discounting, executive skills, and engagement in health behaviors were probed using Pearson's product-moment correlations. The study determined statistical significance at an alpha level of 0.05. A Bonferroni correction was applied to the correlational statistics, resulting in an adjusted alpha value of 0.008. We considered a trend a value between 0.05 and 0.008. The study team analyzed all data using IBM SPSS Statistics 27.0 and RStudio.

3. Results

Demographics: The analysis included a total of 238 participants. The study found a statistically significant difference among groups in age, race, ethnicity, education, and income categories (Table 1).

Examining between-group differences in delay discounting, executive skills, and health behaviors: The study found no differences among substance groups in delay discounting ($F(3, 229) = 0.161$, $p = 0.922$), executive skills ($F(3, 229) = 0.680$, $p = 0.565$), or engagement in health behaviors ($F(3, 229) = 0.549$, $p = 0.649$) after controlling for age, race, ethnicity, education, and income (Fig. 2).

Examining correlations between outcomes of interest: As the study observed no between groups differences in outcomes, we conducted correlational analyses on the full sample of 238 participants. Correlational analyses indicated that health behaviors were significantly positively correlated with executive skills ($r = 0.44$, $p < 0.001$) and abstinence duration ($r = 0.17$, $p = 0.007$) (Fig. 3). Additionally, the study found a significant negative correlation between abstinence duration and delay discounting ($r = -0.14$, $p = 0.031$ [trend]).

4. Discussion

4.1. Behavioral similarities are seen among individuals recovering from different types of substance misuse

In this cross-sectional examination, we found that individuals in recovery from misuse of alcohol, stimulants, opioids, and other substances have similar levels of executive skills and engagement in health behaviors as well as similar delay discounting rates. Although a number of studies have suggested that there are common behavioral and neural mechanisms of the various drugs (Volkow et al., 2019), the recovery process is less studied. Previous studies have reported differences in factors such as motivation, social and personal identity, self-control, and religious involvement among individuals in recovery from different types of substances (Koski-Jannes, 2002; Koski-jännes & Turner, 1999; McBride et al., 1994). The current study adds evidence to this literature that certain other factors (i.e., delay discounting, executive skills, health behaviors) are similar among individuals recovering from misuse of different substances.

This finding has important clinical implications in regard to treatment. Specifically, our findings suggest that treatment plans can be integrated across a range of SUDs, especially for treatments that target

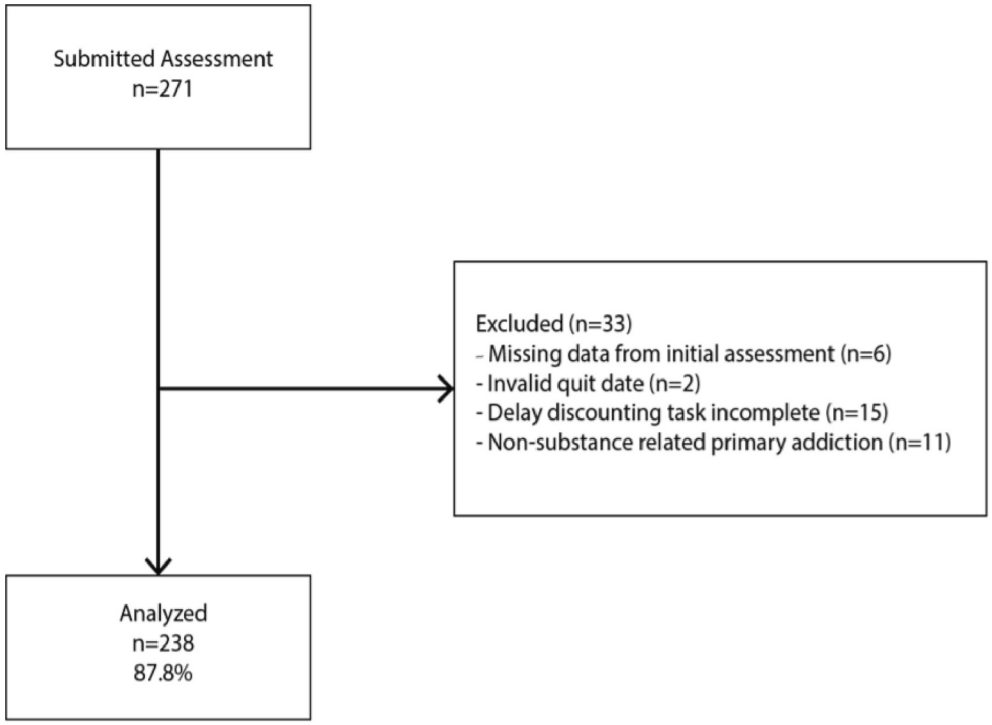

Fig. 1. CONSORT diagram regarding study participation.

Table 1
Participant demographics. Age and abstinence duration are reported as mean (±SEM). All other participant characteristics are reported as percentages. "Other" substances include those who responded prescription pain relievers, cannabis, tranquilizers/depressants, nicotine, dissociative anesthetics, and other. "Other" race includes those who identified as Native American, Pacific Islander, or Other. * Significance at the level of $p<0.05$.

	Alcohol (N = 134)	Stimulants (N = 49)	Opioids (N = 25)	Other (N = 30)	F	p
Age*	50.10 (1.02)	47.08 (1.62)	41.76 (2.59)	47.43 (1.87)	3.897	0.01
Abstinence duration (days)	32223.8 (328.28)	2660.04 (435.43)	2503.56 (705.54)	2329.77 (530.12)	0.817	0.486
Gender					5.765	0.450
% Female	63.4	55.1	52	63.3		
% Male	35.8	40.8	48	36.7		
% Other/prefer not to answer	0.7	4.1	0.0	0.0		
Race*					17.142	0.009
% Caucasian	90.3	71.4	92	80.0		
% African American	2.2	16.3	8	6.7		
% Other/prefer not to answer	7.5	12.2	0.0	13.3		
Ethnicity*					9.496	0.023
% Hispanic	2.2	8.2	0.0	13.3		
% Non-Hispanic	97.8	91.8	100	86.7		
Education*					29.597	0.042
% Some high school	1.5	2.0.	0.0	0.0		
% High school or equivalent	6	16.3	4	10.0		
% Some college	25.4	34.7	52	46.7		
% Associate's degree	11.9	16.3	8	10		
% Bachelor's degree	32.1	24.5	36	23.3		
% Master's degree	15.7	6.1	0.0	3.3		
% Doctoral degree	7.5	0.0	0.0	6.7		
Income*					32.532	0.005
% <$30,000	29.9	49.0	32	43.3		
% $30,000–$49,000	17.9	10.2	36	10		
% $50,000–$69,0000	9.0	18.4	20	20		
% $70,000–$89,000	12.7	2	0.0	0.0		
% $90,000+	19.4	16.3	4	20		
% Prefer not to answer	11.2	4.1	8	6.7		

both delay discounting or executive functioning, neurobehaviors that are supported by the executive system (e.g., the prefrontal cortex). For factors that do vary by group (e.g., social preferences), clinics may consider having separate treatments for individuals with specific SUDs (e.g., alcohol use disorder versus opiate use disorder). The common behavioral indicators found in this study suggest that they may be good targets for complementary interventions supporting abstinence and a healthy recovery process. Episodic future thinking (EFT), an intervention that improves future valuation through imagination of vivid, positive future experiences, engages a network of brain regions involved in the executive circuitry including the hippocampus and frontal cortical regions (Weiler et al., 2010). EFT has successfully been implemented to

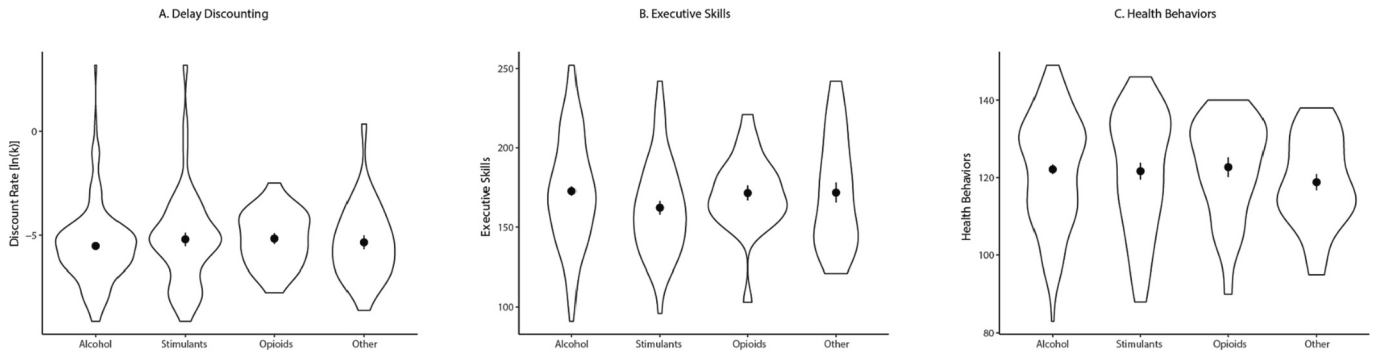

Fig. 2. Between substance-use group comparisons for A) delay discounting, B) executive skills, and C) health behaviors. Data are presented as distributions and mean ± SEM.

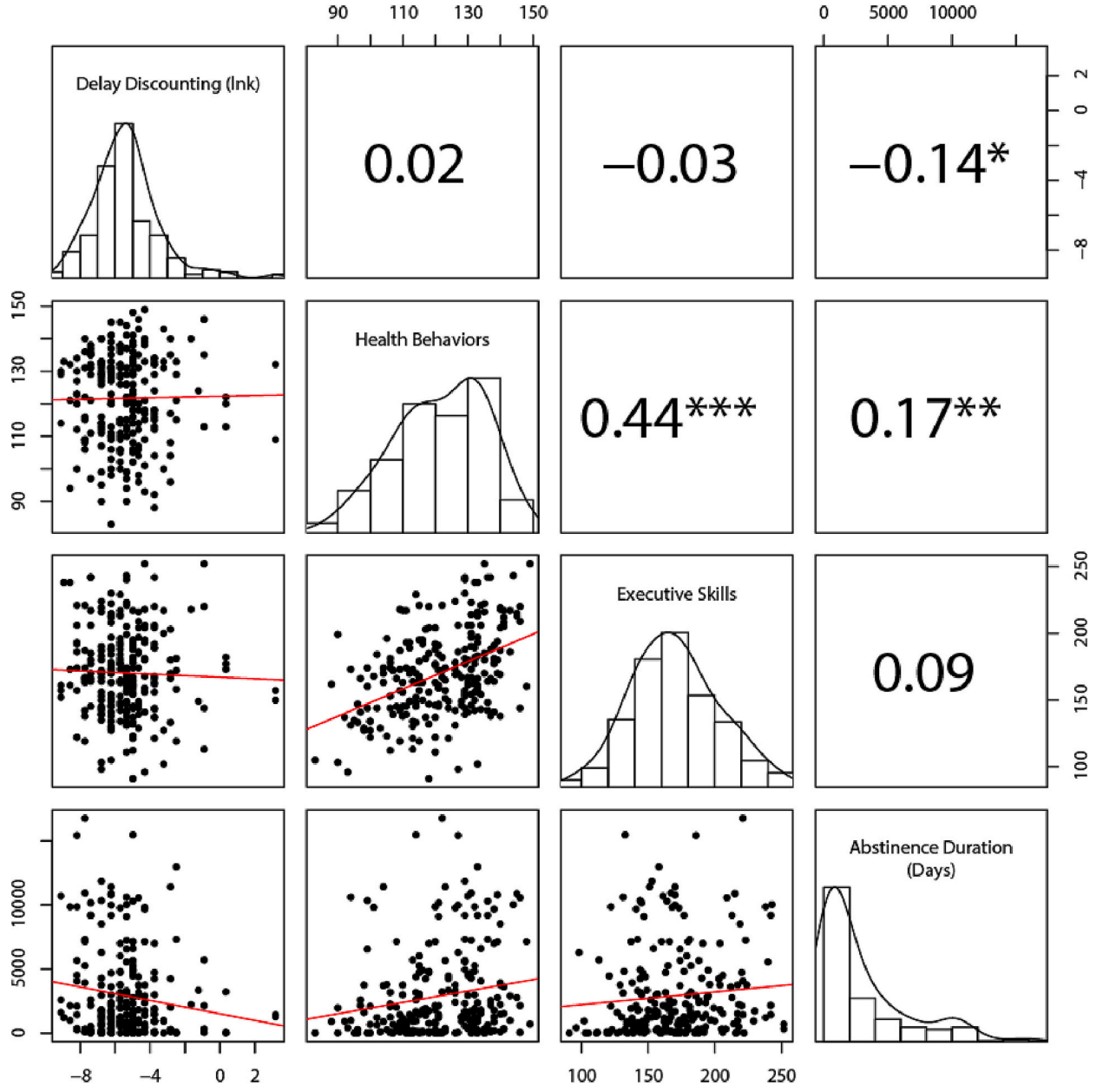

Fig. 3. Correlation scatterplots (bottom), variable distributions (middle), and correlation coefficient (top). *p < 0.05 (trend), **p < 0.008, ***p < 0.001.

decrease alcohol demand in individuals with alcohol dependence (Snider et al., 2016) and to decrease cigarette smoking (Chiou & Wu, 2017; Stein et al., 2016). EFT warrants further investigation to determine its utility to enhance domains of SUD recovery. Goal management training (Alfonso et al., 2011; Anderson et al., 2021; Milliken, 2008), mindfulness (Alfonso et al., 2011; Garland & Howard, 2018; Priddy et al., 2018), and music-based cognitive rehabilitation (Lesiuk, 2010) are other promising interventions to support successful treatment of SUDs through the enhancement of executive functions.

4.2. Executive skills are associated with positive health behaviors in individuals in substance use recovery

We found that executive skills were correlated with engagement in positive health behaviors, including addictive behaviors, preventative or health-related behaviors, driving behaviors, environmental behaviors, and financial behaviors. In line with our findings, previous research has found that executive functions drive engagement in positive health behaviors such as physical activity (Daly et al., 2014) and avoidance of risky health behaviors such as smoking, drinking alcohol, or consuming high-fat foods (Allan et al., 2016). As executive skills are governed by the brain's top-down executive circuitry, our findings suggest that increased activity of executive brain regions is associated with engagement in positive health behaviors in a population of individuals in recovery from substance misuse. The current study is one of the first to show this relationship in a clinical population with substance misuse. As such, our results suggest that psychotherapy, exercise, and other activities capable of regulating executive dysfunction may be beneficial for patients in recovery. The augmentation of an individual's recovery plan with such therapies should be further investigated, utilizing methods to examine executive functioning and associated brain regions, as well as subsequent health behaviors, to corroborate our findings. Brief computerized self-report measures such as the ones used in this study and cognitive tasks could be implemented in person (e.g., in a clinic waiting room) or remotely to assess executive functioning and health behaviors repeatedly over time. Promising results would be impactful motivators for patients and help to develop a basis for therapies that alter the executive system and promote maintained recovery.

Executive functioning is critical as it enables top-down control of thoughts, emotions, and behavior (Baumeister et al., 2007; Hofmann et al., 2012). The prefrontal brain regions that support executive function, including the medial prefrontal cortex, enable our ability to plan and execute goal-directed behaviors (Euston et al., 2012). In this instance, an important goal-directed behavior is the choice to not use alcohol and/or drugs—the goal of sustaining abstinence. Engaging in positive health behaviors beyond abstinence is an important aim of the recovery process as substance use recovery is a multifaceted process (Inanlou et al., 2020; Kaskutas et al., 2014; Laudet, 2007). Positive health behaviors such as maintaining diet and exercise habits, following a doctor's treatment plans, safe driving practices, making sound financial decisions, and using protection during sex are instrumental in leading a healthy lifestyle during recovery. In fact, research indicates that engaging in a healthy lifestyle enhances quality of life and helps promote successful recovery in a range of relapsing-remitting diseases (Singer et al., 2001).

4.3. Abstinence duration is associated with increased future valuation and health behaviors

In line with our hypothesis, we found that abstinence duration was significantly correlated with increased future valuation (i.e., decreased delay discounting), a finding that aligns with previous studies of ours and others indicating that delay discounting is related to severity of drug use (Albein-Urios et al., 2012; Johnson et al., 2007; Vuchinich & Simpson, 1998), remission status (Athamneh et al., 2020), and time in recovery (Athamneh et al., 2019; Tomlinson et al., 2020). That is, as time in recovery progresses and drug use becomes less of a focus in an individual's life, the valuation of the future increases. Additionally, we found that as abstinence duration increases, individuals are more likely to engage in positive health behaviors. Though research has shown that health behaviors are impaired in SUDs (e.g., poor nutrition, lack of physical activity, decreased social relationships), surprisingly little empirical evidence has examined health behaviors during the recovery process. Clinical work, however, suggests that engagement in a range of health behaviors supports the enhanced quality of life that is needed for sustained recovery (Laudet, 2011; Whitley & Drake, 2010). Interestingly, Dennis et al. (2007) conducted a study of 1162 individuals who entered SUD treatment programs and were followed for up to 8 years. They investigated a range of aspects of recovery, including physical and mental health, coping responses, legal involvement, vocational involvement, housing, peers, and social and spiritual support. First, they found that 86% of the study population sustained abstinence at the 5+ year follow-up period. Second, they found that other aspects of recovery occurred at different rates and times. For example, following 1 year of abstinence, the number of days worked increased and financial problems decreased, with significant reductions in living below the poverty line occurring at 3 years of abstinence. Additionally, the duration of abstinence was significantly associated with reduced environmental risks, increased number of sober friends, level of social and spiritual support, and an increase in self-efficacy to resist relapse. Future work will need to investigate whether interventions such as EFT may help to expedite the rate of recovery in these other essential areas of life.

Contrary to our initial hypothesis, executive skills were not associated with abstinence duration. While some previous research has shown a link between abstinence duration and executive functioning (Farhadian et al., 2017; Zinn et al., 2004), others have suggested that this improvement in executive function over time is limited. Executive impairments may persist during long-term abstinence (Fein et al., 2004) and any improvements may not be of clinical significance (Bates et al., 2005). Of clinical relevance, however, individuals are able to achieve and maintain successful recovery despite some persistent impairments in executive functions (Fein et al., 2004).

4.4. Limitations and future directions

While this study brought new insight and perspective regarding the relationships between health behaviors, executive skills, and delay discounting, we should note several limitations. First, the study recruited participants from the IQRR, which is a registry of people who self-report some form of addictive behavior or substance misuse and voluntarily become a member of the recovery community and participate in research. Hence, the results of this study may be biased toward people in recovery who are prone to seek support and acknowledge the grave risks of SUDs. As many people join the IQRR in search of accountability or inspiration in addiction recovery, IQRR members may be more motivated and less likely to relapse than the general recovery population. Additionally, the study used a self-report questionnaire to assess executive skills, which relies on participants' subjective assessment of their executive skills; however, performance on a revised version of this questionnaire was shown to be associated with other neurocognitive tasks of executive function as well as academic performance (Strait et al., 2020). Future studies may use performance-based cognitive tasks, such as the Stroop Task or Eriksen Flanker Task, to evaluate executive functions. Additionally, future studies should consider using other measures to assess quality of recovery such as days engaged in work, sport, or other leisure, nonsubstance related activities. Last, our study was cross-sectional, limiting our ability to investigate these relationships over time and the temporal relationships among variables. Importantly, the cross-sectional nature of the study precludes us from making any conclusions about causality or directionality. Future studies could also consider conducting additional statistical analyses, such as path modeling, which can allow researchers to assess both mediation and

moderation of a range of variables. That is, other factors might influence the strength of the relationships investigated in the current study including stress (e.g., stress related to health, occupation, or relationships) or comorbid diagnoses (e.g., depression or anxiety). Future longitudinal studies are warranted to examine causal relationships and outcomes over time.

5. Conclusion

In this observational study of an international group of individuals in recovery from various SUDs (i.e., alcohol, stimulants, opioids, other), we found that delay discounting, executive skills, and engagement in health behaviors were similar in the process of recovery from different substances. We further found that abstinence duration was significantly associated with future valuation and health behaviors, which was additionally associated with executive skills. These findings suggest that common behavioral mechanisms, which may be driven by the executive system, support success in recovery. In light of these findings, we suggest that interventions to target the executive system including EFT, exercise, or meditation should be utilized to promote successful recovery. Future research should explore these interventions to target health behaviors and other prosocial behaviors that will support success in recovery.

Credit authorship contribution statement

WKB, JCB, and LNA conceptualized the study. JCB, MKS, and LNA ran all study procedures. MKS and HW conducted data cleaning. JCB, MKS, and HW conducted all data analysis. JCB, MKS, LNA, and HW wrote the article and created all figures and tables. All authors contributed to the article and approved the submitted version. WKB provided funding for the project.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.josat.2023.209007.

References

Albein-Urios, N., Martinez-González, J. M., Lozano, O., Clark, L., & Verdejo-García, A. (2012). Comparison of impulsivity and working memory in cocaine addiction and pathological gambling: Implications for cocaine-induced neurotoxicity. *Drug and Alcohol Dependence, 126*(1–2), 1–6. https://doi.org/10.1016/j.drugalcdep.2012.03.008

Alfonso, J. P., Caracuel, A., Delgado-Pastor, L. C., & Verdejo-García, A. (2011). Combined goal management training and mindfulness meditation improve executive functions and decision-making performance in abstinent polysubstance abusers. *Drug and Alcohol Dependence, 117*(1), 78–81. https://doi.org/10.1016/j.drugalcdep.2010.12.025

Allan, J. L., McMinn, D., & Daly, M. (2016). A bidirectional relationship between executive function and health behavior: Evidence, implications, and future directions. *Frontiers in Neuroscience, 10*, 386. https://doi.org/10.3389/fnins.2016.00386

Anderson, A. C., Youssef, G. J., Robinson, A. H., Lubman, D. I., & Verdejo-Garcia, A. (2021). Cognitive boosting interventions for impulsivity in addiction: A systematic review and meta-analysis of cognitive training, remediation and pharmacological enhancement. *Addiction*. https://doi.org/10.1111/add.15469

Athamneh, L. N., DeHart, W. B., Pope, D., Mellis, A. M., Snider, S. E., Kaplan, B. A., & Bickel, W. K. (2019). The phenotype of recovery III: Delay discounting predicts abstinence self-efficacy among individuals in recovery from substance use disorders. *Psychology of Addictive Behaviors: Journal of the Society of Psychologists in Addictive Behaviors, 33*(3), 310–317. https://doi.org/10.1037/adb0000460

Athamneh, L. N., Lemos, R. F., Basso, J. C., Tomlinson, D. C., Craft, W. H., Stein, M. D., & Bickel, W. K. (2020). The phenotype of recovery II: The association between delay discounting, self-reported quality of life, and remission status among individuals in recovery from substance use disorders. In *Experimental and clinical psychopharmacology*. https://doi.org/10.1037/pha0000389

Bates, M. E., Voelbel, G. T., Buckman, J. F., Labouvie, E. W., & Barry, D. (2005). Short-term neuropsychological recovery in clients with substance use disorders. *Alcoholism, Clinical and Experimental Research, 29*(3), 367–377. https://doi.org/10.1097/01.alc.0000156131.88125.2a

Baumeister, Schmeichel, & Vohs. (2007). *Self-regulation and the executive function: The self as controlling agent. Social psychology: Handbook of*. https://www.avc.edu/sites/default/files/studentservices/lc/PaperonSelf-Regulation.pdf.

Bickel, W. K., Athamneh, L. N., Basso, J. C., Mellis, A. M., DeHart, W. B., Craft, W. H., & Pope, D. (2019). Excessive discounting of delayed reinforcers as a trans-disease process: Update on the state of the science. *Current Opinion in Psychology, 30*, 59–64. https://doi.org/10.1016/j.copsyc.2019.01.005

Bickel, W. K., Jarmolowicz, D. P., Mueller, E. T., Koffarnus, M. N., & Gatchalian, K. M. (2012). Excessive discounting of delayed reinforcers as a trans-disease process contributing to addiction and other disease-related vulnerabilities: Emerging evidence. *Pharmacology & Therapeutics, 134*(3), 287–297. https://doi.org/10.1016/j.pharmthera.2012.02.004

Bickel, W. K., Johnson, M. W., Koffarnus, M. N., MacKillop, J., & Murphy, J. G. (2014). The behavioral economics of substance use disorders: Reinforcement pathologies and their repair. *Annual Review of Clinical Psychology, 10*, 641–677. https://doi.org/10.1146/annurev-clinpsy-032813-153724

Bickel, W. K., Koffarnus, M. N., Moody, L., & Wilson, A. G. (2014). The behavioral- and neuro-economic process of temporal discounting: A candidate behavioral marker of addiction. *Neuropharmacology, 76*(Pt B), 518–527. https://doi.org/10.1016/j.neuropharm.2013.06.013

Bickel, W. K., Mellis, A. M., Snider, S. E., Athamneh, L. N., Stein, J. S., & Pope, D. A. (2018). 21st century neurobehavioral theories of decision making in addiction: Review and evaluation. *Pharmacology, Biochemistry, and Behavior, 164*, 4–21. https://doi.org/10.1016/j.pbb.2017.09.009

Bickel, W. K., Miller, M. L., Yi, R., Kowal, B. P., Lindquist, D. M., & Pitcock, J. A. (2007). Behavioral and neuroeconomics of drug addiction: Competing neural systems and temporal discounting processes. *Drug and Alcohol Dependence, 90*(Suppl. 1), S85–S91. https://doi.org/10.1016/j.drugalcdep.2006.09.016

Chiou, W.-B., & Wu, W.-H. (2017). Episodic future thinking involving the nonsmoking self can induce lower discounting and cigarette consumption. *Journal of Studies on Alcohol and Drugs, 78*(1), 106–112. https://doi.org/10.15288/jsad.2017.78.106

Daly, M., McMinn, D., & Allan, J. L. (2014). A bidirectional relationship between physical activity and executive function in older adults. *Frontiers in Human Neuroscience, 8*, 1044. https://doi.org/10.3389/fnhum.2014.01044

Daugherty, J. R., & Brase, G. L. (2010). Taking time to be healthy: Predicting health behaviors with delay discounting and time perspective. In *, Vol. 48, Issue 2. Personality and individual differences* (pp. 202–207). https://doi.org/10.1016/j.paid.2009.10.007

Dawson, P., & Guare, R. (2010). Executive skills in children and adolescents: A practical guide to assessment and intervention. In*The Guilford practical intervention in the schools series* (2nd ed.,, *2* p. 234) https://psycnet.apa.org/fulltext/2010-13174-000.pdf.

Dawson, P., & Guare, R. (2012). *Coaching students with executive skills deficits*. Guilford Press. https://play.google.com/store/books/details?id=Oko3EUkub_wC.

Dawson, P., & Guare, R. (2018). *Executive skills in children and adolescents, third edition: A practical guide to assessment and intervention*. Guilford Publications. https://play.google.com/store/books/details?id=YQ1aDwAAQBAJ.

DeHart, W. B., Snider, S. E., Pope, D. A., & Bickel, W. K. (2020). A reinforcer pathology model of health behaviors in individuals with obesity. *Health Psychology: Official Journal of the Division of Health Psychology, American Psychological Association, 39*(11), 966–974. https://doi.org/10.1037/hea0000995

Dennis, M. L., Foss, M. A., & Scott, C. K. (2007). An eight-year perspective on the relationship between the duration of abstinence and other aspects of recovery. *Evaluation Review, 31*(6), 585–612. https://doi.org/10.1177/0193841X07307771

Ellis, C., Hoffman, W., Jaehnert, S., Plagge, J., Loftis, J. M., Schwartz, D., & Huckans, M. (2016). Everyday problems with executive dysfunction and impulsivity in adults recovering from methamphetamine addiction. *Addictive Disorders & Their Treatment, 15*(1), 1–5. https://doi.org/10.1097/ADT.0000000000000059

Euston, D. R., Gruber, A. J., & McNaughton, B. L. (2012). The role of medial prefrontal cortex in memory and decision making. *Neuron, 76*(6), 1057–1070. https://doi.org/10.1016/j.neuron.2012.12.002

Farhadian, M., Akbarfahimi, M., Hassani Abharian, P., Hosseini, S. G., & Shokri, S. (2017). Assessment of executive functions in methamphetamine-addicted individuals: Emphasis on duration of addiction and abstinence. *Basic and Clinical Neuroscience, 8*(2), 147–153. https://doi.org/10.18869/nirp.bcn.8.2.147

Fein, G., Klein, L., & Finn, P. (2004). Impairment on a simulated gambling task in long-term abstinent alcoholics. *Alcoholism, Clinical and Experimental Research, 28*(10), 1487–1491. https://doi.org/10.1097/01.alc.0000141642.39065.9b

Fernández-Serrano, M. J., Pérez-García, M., Schmidt Río-Valle, J., & Verdejo-García, A. (2010). Neuropsychological consequences of alcohol and drug abuse on different components of executive functions. *Journal of Psychopharmacology, 24*(9), 1317–1332. https://doi.org/10.1177/0269881109349841

García-Rodríguez, O., Secades-Villa, R., Weidberg, S., & Yoon, J. H. (2013). A systematic assessment of delay discounting in relation to cocaine and nicotine dependence. *Behavioural Processes, 99*, 100–105. https://doi.org/10.1016/j.beproc.2013.07.007

Garland, E. L., & Howard, M. O. (2018). Mindfulness-based treatment of addiction: Current state of the field and envisioning the next wave of research. *Addiction Science & Clinical Practice, 13*(1), 14. https://doi.org/10.1186/s13722-018-0115-3

Gustavson, D. E., Stallings, M. C., Corley, R. P., Miyake, A., Hewitt, J. K., & Friedman, N. P. (2017). Executive functions and substance use: Relations in late

adolescence and early adulthood. *Journal of Abnormal Psychology, 126*(2), 257–270. https://doi.org/10.1037/abn0000250

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences, 16*(3), 174–180. https://doi.org/10.1016/j.tics.2012.01.006

Inanlou, M., Bahmani, B., Farhoudian, A., & Rafiee, F. (2020). Addiction recovery: A systematized review. *Iranian Journal of Psychiatry, 15*(2), 172–181. https://www.ncbi.nlm.nih.gov/pubmed/32426014.

Johnson, M. W., Bickel, W. K., & Baker, F. (2007). Moderate drug use and delay discounting: A comparison of heavy, light, and never smokers. *Experimental and Clinical Psychopharmacology, 15*(2), 187–194. https://doi.org/10.1037/1064-1297.15.2.187

Kaskutas, L. A., Borkman, T. J., Laudet, A., Ritter, L. A., Witbrodt, J., Subbaraman, M. S., Stunz, A., & Bond, J. (2014). Elements that define recovery: The experiential perspective. *Journal of Studies on Alcohol and Drugs, 75*(6), 999–1010. https://doi.org/10.15288/jsad.2014.75.999

Koffarnus, M. N., & Bickel, W. K. (2014). A 5-trial adjusting delay discounting task: Accurate discount rates in less than one minute. *Experimental and Clinical Psychopharmacology, 22*(3), 222–228. https://doi.org/10.1037/a0035973

Koski-Jannes, A. (2002). Social and personal identity projects in the recovery from addictive behaviours. *Addiction Research & Theory, 10*(2), 183–202.

Koski-jännes, A., & Turner, N. (1999). Factors influencing recovery from different addictions. *Addiction Research & Theory, 7*(6), 469–492. https://doi.org/10.3109/16066359909004401

Laudet, A. B. (2007). What does recovery mean to you? Lessons from the recovery experience for research and practice. *Journal of Substance Abuse Treatment, 33*(3), 243–256. https://doi.org/10.1016/j.jsat.2007.04.014

Laudet, A. B. (2011). The case for considering quality of life in addiction research and clinical practice. *Addiction Science & Clinical Practice, 6*(1), 44–55. https://www.ncbi.nlm.nih.gov/pubmed/22003421.

Lesiuk, T. L. (2010). A rationale for music-based cognitive rehabilitation toward prevention of relapse in drug addiction. *Music Therapy Perspectives, 28*(2), 124–130. https://doi.org/10.1093/mtp/28.2.124

Mazur, J. E. (1987). Commons, ML.; Mazur, JE.; Nevin, JA. In *An adjusting procedure for studying delayed reinforcement* (pp. 55–73) https://books.google.com/books?hl=en&lr=&id=1q5mAgAAQBAJ&oi=fnd&pg=PA55&dq=An+adjusting+procedure+for+studying+delayed+reinforcement&ots=eOlASJsa4u&sig=dGVhp_-daTrJAYdKCS3Ci0CY4Kk.

McBride, C. M., Curry, S. J., Stephens, R. S., Wells, E. A., Roffman, R. A., & Hawkins, J. D. (1994). Intrinsic and extrinsic motivation for change in cigarette smokers, marijuana smokers, and cocaine users. *Psychology of Addictive Behaviors: Journal of the Society of Psychologists in Addictive Behaviors, 8*(4), 243–250. https://doi.org/10.1037/0893-164X.8.4.243

McCabe, S. E., West, B. T., Jutkiewicz, E. M., & Boyd, C. J. (2017). Multiple DSM-5 substance use disorders: A national study of US adults. *Human Psychopharmacology, 32*(5), Article e2625. https://doi.org/10.1002/hup.2625

McLellan, A. T., Lewis, D. C., O'Brien, C. P., & Kleber, H. D. (2000). Drug dependence, a chronic medical illness: Implications for treatment, insurance, and outcomes evaluation. *JAMA: TheJournal of the American Medical Association, 284*(13), 1689–1695. https://doi.org/10.1001/jama.284.13.1689

Merikangas, K. R., & McClair, V. L. (2012). Epidemiology of substance use disorders. *Human Genetics, 131*(6), 779–789. https://doi.org/10.1007/s00439-012-1168-0

Milliken, R. (2008). Intervening in the cycle of addiction, violence, and shame: A dance/movement therapy group approach in a jail addictions program. *Journal of Groups in Addiction & Recovery, 3*(1–2), 5–22. https://doi.org/10.1080/15560350802157346

Neale, J., Finch, E., Marsden, J., Mitcheson, L., Rose, D., Strang, J., Tompkins, C., Wheeler, C., & Wykes, T. (2014). How should we measure addiction recovery? Analysis of service provider perspectives using online Delphi groups. *Drugs: Education, Prevention and Policy, 21*(4), 310–323. https://doi.org/10.3109/09687637.2014.918089

Peeters, M., Janssen, T., Monshouwer, K., Boendermaker, W., Pronk, T., Wiers, R., & Vollebergh, W. (2015). Weaknesses in executive functioning predict the initiating of adolescents'alcohol use. *Developmental Cognitive Neuroscience, 16*, 139–146. https://doi.org/10.1016/j.dcn.2015.04.003

Perry, J. L., Larson, E. B., German, J. P., Madden, G. J., & Carroll, M. E. (2005). Impulsivity (delay discounting) as a predictor of acquisition of IV cocaine self-administration in female rats. *Psychopharmacology, 178*(2–3), 193–201. https://doi.org/10.1007/s00213-004-1994-4

Phung, Q. H., Snider, S. E., Tegge, A. N., & Bickel, W. K. (2019). Willing to work but not to wait: Individuals with greater alcohol use disorder show increased delay discounting across commodities and less effort discounting for alcohol. *Alcoholism, Clinical and Experimental Research, 43*(5), 927–936. https://doi.org/10.1111/acer.13996

Pope, H. G., Jr., Gruber, A. J., Hudson, J. I., Huestis, M. A., & Yurgelun-Todd, D. (2002). Cognitive measures in long-term cannabis users. *Journal of Clinical Pharmacology, 42*(S1), 41S–47S. https://doi.org/10.1002/j.1552-4604.2002.tb06002.x

Priddy, S. E., Howard, M. O., Hanley, A. W., Riquino, M. R., Friberg-Felsted, K., & Garland, E. L. (2018). Mindfulness meditation in the treatment of substance use disorders and preventing future relapse: Neurocognitive mechanisms and clinical implications. *Substance Abuse and Rehabilitation, 9*, 103–114. https://doi.org/10.2147/SAR.S145201

Schmidt, T. P., Pennington, D. L., Cardoos, S. L., Durazzo, T. C., & Meyerhoff, D. J. (2017). Neurocognition and inhibitory control in polysubstance use disorders: Comparison with alcohol use disorders and changes with abstinence. *Journal of Clinical and Experimental Neuropsychology, 39*(1), 22–34. https://doi.org/10.1080/13803395.2016.1196165

Shmulewitz, D., Greene, E. R., & Hasin, D. (2015). Commonalities and differences across substance use disorders: Phenomenological and epidemiological aspects. *Alcoholism, Clinical and Experimental Research, 39*(10), 1878–1900. https://doi.org/10.1111/acer.12838

Singer, B. H., Ryff, C. D., & National Research Council (US) Committee on Future Directions for Behavioral and Social Sciences Research at the National Institutes of Health. (2001). *Positive health: Resilience, recovery, primary prevention, and health promotion*. National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK43790/.

Snider, S. E., DeHart, W. B., Epstein, L. H., & Bickel, W. K. (2018). Does delay discounting predict maladaptive health and financial behaviors in smokers? *Health Psychology: Official Journal of the Division of Health Psychology*. https://doi.org/10.1037/hea0000695. American Psychological Association.

Snider, S. E., LaConte, S. M., & Bickel, W. K. (2016). Episodic future thinking: Expansion of the temporal window in individuals with alcohol dependence. *Alcoholism, Clinical and Experimental Research, 40*(7), 1558–1566. https://doi.org/10.1111/acer.13112

Stein, J. S., Wilson, A. G., Koffarnus, M. N., Daniel, T. O., Epstein, L. H., & Bickel, W. K. (2016). Unstuck in time: Episodic future thinking reduces delay discounting and cigarette smoking. *Psychopharmacology, 233*(21–22), 3771–3778. https://doi.org/10.1007/s00213-016-4410-y

Strait, J. E., Dawson, P., Walther, C. A. P., Strait, G. G., Barton, A. K., & Brunson McClain, M. (2020). Refinement and psychometric evaluation of the executive skills questionnaire-revised. *Contemporary School Psychology, 24*(4), 378–388. https://doi.org/10.1007/s40688-018-00224-x

Substance Abuse and Mental Health Services Administration. (2019). Key substance use and mental health indicators in the United States: Results from the 2018 National Survey on Drug Use and Health. https://www.samhsa.gov/data/.

Tomlinson, D. C., Tegge, A. N., Athamneh, L. N., & Bickel, W. K. (2020). The phenotype of recovery IV: Delay discounting predicts perceived stress and a chance locus of control in individuals in recovery from substance use disorders. *Addictive Behaviors Reports, 12*, Article 100320. https://doi.org/10.1016/j.abrep.2020.100320

Volkow, N. D., Michaelides, M., & Baler, R. (2019). The neuroscience of drug reward and addiction. *Physiological Reviews, 99*(4), 2115–2140. https://doi.org/10.1152/physrev.00014.2018

Vuchinich, R. E., & Simpson, C. A. (1998). Hyperbolic temporal discounting in social drinkers and problem drinkers. *Experimental and Clinical Psychopharmacology, 6*(3), 292–305. https://doi.org/10.1037//1064-1297.6.3.292

Weiler, J. A., Suchan, B., & Daum, I. (2010). When the future becomes the past: Differences in brain activation patterns for episodic memory and episodic future thinking. *Behavioural Brain Research, 212*(2), 196–203. https://doi.org/10.1016/j.bbr.2010.04.013

Whitley, R., & Drake, R. E. (2010). Recovery: A dimensional approach. *Psychiatric Services, 61*(12), 1248–1250. https://doi.org/10.1176/ps.2010.61.12.1248

Witkiewitz, K., Montes, K. S., Schwebel, F. J., & Tucker, J. A. (2020). What is recovery? *Alcohol Research: Current Reviews, 40*(3), 01. https://doi.org/10.35946/arcr.v40.3.01

Zinn, S., Stein, R., & Swartzwelder, H. S. (2004). Executive functioning early in abstinence from alcohol. *Alcoholism, Clinical and Experimental Research, 28*(9), 1338–1346. https://doi.org/10.1097/01.alc.0000139814.81811.62