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Review

Measurement of substance-free reinforcement in addiction: A systematic review

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HIGHLIGHTS

- Engagement with drug-free (alternative) activities is protective against drug use.
- Applied, self-report methods exist derived from principles of reinforcement.
- There is lack of consensus in the applied measurement of alternative reinforcement.
- Different measurement approaches are best suited for idiosyncratic clinical issues.
- Measures can enhance intervention feedback and tracking and are useful as outcomes.

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ABSTRACT

A robust body of theoretical and experimental work highlights the influence of alternative, substance-free rewards on decisions to use alcohol and other drugs. However, translational applications have been limited in part by the lack of consensus on how to measure substance-free reinforcement in applied and clinical settings. The current study summarizes extant research utilizing self-report reinforcement or reward methodologies, and critically reviews the psychometric properties of the available measures. These studies (N = 50) fell into three categories: measures of recent substance-related and substance-free activity participation and enjoyment (n = 32), measures of time or monetary resource allocation (n = 15), and rating scale measures of reward availability and experience (n = 8). The available research suggests that, consistent with experimental laboratory research and with behavioral economic predictions, there is an inverse relation between substance-free reinforcement and substance use. These studies also support the clinical utility of these measures in predicting substance use severity and course. Reinforcement measures could be improved by enhancing content validity, multimethod convergent validity, and generalizability.

1. Introduction

Substance addiction entails the repeated use of a drug of abuse despite deleterious health and social consequences. This persistent use is thought to be due to the reinforcing effects of the drug, which maintain consistent efforts to obtain additional drug doses even when the behavioral or monetary response cost is high. Behavioral theories of choice, such as behavioral economics, are molar theories of behavior that consider reinforcement in the context of the environment and posit that the allocation of resources to an activity (response rate) is related to the reinforcing properties of a given stimulus relative to the other available stimuli (Herrnstein, 1974). Behavioral economic theory thus highlights the importance of deficits in substance-free reinforcement (also known as alternative reinforcement) in the development and maintenance of drug addiction in addition to the reinforcing efficacy of the drug itself (Bickel, Johnson, Koffarnus, MacKillop, & Murphy, 2014; Lamb & Ginsburg, 2018; Vuchinich & Heather, 2003).

This theoretical proposition has been largely supported in laboratory studies that quantify an organism's response rate for a drug as a function of the availability and amount of an alternative drug-free reinforcer (e.g., food, saccharin, exercise). In the seminal rat park experiments, Alexander and colleagues manipulated availability of activities (e.g., running wheel) and social companions (e.g., other rats in the same cage) and found that rats in the enriched condition self-administered significantly less morphine (Alexander, Beyerstein, Hadaway & Coambs, 1981). Subsequent research demonstrated that the

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availability of novel objects and exercise (e.g., wheel-running) also attenuates drug self-administration in animal models, suggesting that, in the presence of robust alternative reinforcers, substance use behavior may naturally diminish (Cosgrove, Hunter, & Carroll, 2002; Robison, Alessi, & Thanos, 2018; see also Gage & Sumnall, 2018). Further, removing substance-free reinforcers from the environment can increase drug self-administration (Ginsburg & Lamb, 2018), while increasing environmental enrichment can reduce self-administration and even prevent activation of reward neurocircuitry associated with drug use in the presence of the drug (Solinas, Chauvet, Thiriet, El Rawas, & Jaber, 2008). Despite this, evidence also suggests that individual differences exist in the sensitivity to alternatives, and a small percentage of rats (~15%) seem to always choose alcohol, even in the presence of a high-value alternative reward (Augier et al., 2018).

Laboratory studies with human drug users also suggest that levels of drug use are influenced by the availability of alternative reinforcers. For example, one study found that choices to consume alcohol were inversely related to the amount of alternative reinforcer (i.e., money) available (Vuchinich & Tucker, 1983). Similarly, among cocaine users, intravenous cocaine administration is a potent reinforcer when a monetary alternative is not available; however, as the value of the monetary alternative increases, cocaine self-administration decreases (Higgins, Bickel, & Hughes, 1994). These findings were extended in a naturalistic study attempting to explore the influence of non-monetary reinforcers on substance use (Correia, Benson, & Carey, 2005). In this study, college students reporting any substance use were randomly assigned to three conditions: substance reduction (participants were asked to reduce substance use for the period of the study), activity increase (participants were asked to increase exercise or creative activities for the duration of the study without any mention of substance use reduction), and no-change control. After four weeks, those who were asked to increase drug-free activities (exercise or creative activities) reported reductions in drinking similar to those who are asked to decrease their drinking, compared to stable use across time in the no-change control group (Correia et al., 2005).

In an important population-level extension of this work, systematic efforts to increase afterschool and evening alternatives for teens resulted in substantial decreases in adolescent substance misuse in Iceland (Kristjansson et al., 2016; Kristjansson, James, Allegrante, Sigfusdottir, & Helgason, 2010). As a result of these compelling laboratory and population findings, substance-free reinforcement is now recognized as a significant treatment target (McKay, 2017), and there are now a number of evidence-based treatments that attempt to increase substance-free reinforcement, including contingency management, community reinforcement, behavioral activation, and the substance-free activity session (Boswell, Iles, Gallagher, & Farchione, 2017; Carey, Carey, Henson, Maisto, & DeMartini, 2011; Meyers, Roozen, & Smith, 2011; Murphy et al., 2012; Petry, Alessi, Olmstead, Rash, & Zajac, 2017). Contingency management approaches are especially effective and have been disseminated in many settings (DePhilippis, Petry, Bonn-Miller, Rosenbach, & McKay, 2018; Petry et al., 2017). Wide-spread dissemination for many other interventions may still be limited by the costs of the contingencies, concern about relapse following discontinuation of the contingencies, and a hesitancy on the part of some funding agencies or treatment centers to pay some individual to stop engaging in drug use when others abstain without such incentives. Overall, however, these reinforcement-based interventions are promising, but knowledge of the ideal approaches for increasing substance-free reinforcement, and the extent to which it acts as a mechanism of behavior change, is limited by the absence of a uniform and valid measurement approach.

2. Current study

Behavioral economic indices such as delay discounting and substance demand have been extensively studied and specific quantitative methods for deriving indices have been thoroughly explicated (Bickel & Yi, 2008; Hursh & Silberberg, 2008; Koffarnus, Franck, Stein, & Bickel, 2015; Reimers, Maylor, Stewart, & Chater, 2009). Further, recent efforts to standardize measurement methods for other theoretically relevant etiological variables (Kwako, Momenan, Litten, Koob, & Goldman, 2015), such as executive functioning, negative emotionality, and incentive salience of the addictive behavior, highlight the importance of these variables and may prove fruitful in understanding addiction. However, a recent structural regression identified proportionate substance-free reinforcement as the most robust predictor of alcohol consumption and problems among college students, over and above executive control and incentive salience variables (Acuff, Soltis, Dennhardt, Berlin, & Murphy, 2018). Thus, substance-free and substance-related reinforcement are key concepts in behavioral economic and other theories of addiction, including in disease models (Volkow, Fowler, & Wang, 2003), but have received comparatively less attention in the literature compared to the other factors listed above. Findings within the laboratory are robust, however, this relation has not yet been well elucidated in human studies, partially due to the heterogeneity of measurement approaches. Two reviews have examined substance-free reinforcement and substance misuse within the context of human studies. Higgins, Heil, and Lussier (2004) generally reviewed the conceptual basis for studying substance-free reinforcement. Heinz, Lilje, Kassel, and de Wit (2012) specifically reviewed and explained measurement options for behavioral economic indices in general, although the results of studies employing various measurement approaches were not systematically examined. Several human studies examining substance-free reinforcement have been published since 2012, including studies using paradigms not included in the Heinz review. Thus, the goal of current study is to 1) elucidate the nature of the relation between substance misuse and substance-free reinforcement and 2) to provide a critical review of available measurement approaches; and 3) to provide recommendations for self-report measurement of substance-free reinforcement in human clinical and naturalistic studies.

3. Methods

3.1. Search strategy and selection of studies

We used PubMed and PsycINFO to search for relevant studies. Search terms were known measure names or common terms used in the field implicating substance-free reinforcement and included adolescent reinforcement survey schedule, alternative reinforcement, alternative reinforcers, behavioral activation, behavioral economics measure, behavioral theories of choice, diminished alternative reinforcement, discretionary expenditure, expanded timeline followback, monetary expenditure, pleasant events schedule, reinforcement ratio, substance-free activity, substance-free enjoyment, substance-free frequency, substance-free reinforcement, time allocation, and substitute reinforcer. The search terms were used in conjunction with substance use keywords (substance use, or alcohol, or alcoholic, or heavy drinking, or marijuana, or THC, or cigarettes, or smoking, or nicotine, or tobacco, or cocaine, or crack, or methamphetamine, or opioids, or opiates, or heroin). The search included all published studies through January 22, 2019.

3.1.1. Inclusion/exclusion criteria

Studies included in the systematic review met the following criteria: (i) published, peer-reviewed original reports examining humans; (ii) alcohol/substance use as a primary quality in the population of interest; (iii) use of behavioral or self-report measurement technique that purposefully examines substance-free reinforcement as defined by frequency, frequency and enjoyment, or behavioral or monetary resource allocation in the real world, or specifically assesses reward experience; and (iv) studies that were reported in English. Study eligibility was determined in two steps. First, the first author read through the title and

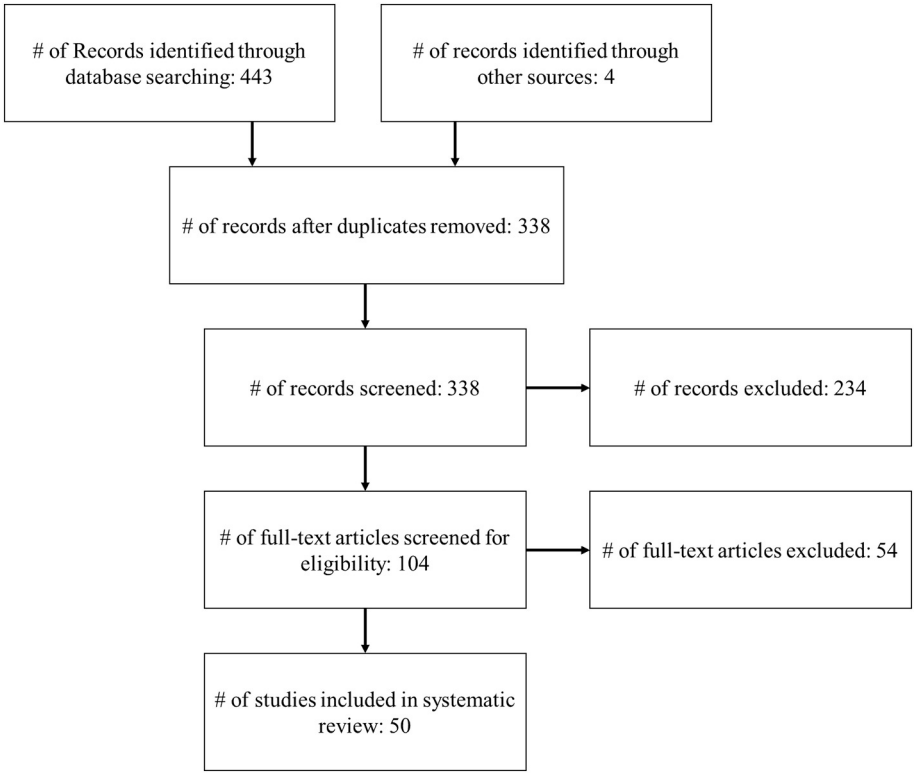

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) inclusion flow diagram.

abstract of each article and marked whether they would be included in the study. The second author went over the results as a secondary check. Next, the full-text article for any study that was deemed eligible was recovered. The first author then read through the abstract and methods section for each article; the second author went over these results as a secondary check.

4. Results

4.1. Search results

The online database identified 443 (338 unique) articles, and four were identified through other sources. After screening, 104 articles were selected for full-text review. We omitted manuscripts that did not use one of the previously defined measurement methods or that did not directly measure substance use or misuse. Of the full-text articles screened, 50 met eligibility criteria and were included in the systematic review. Fig. 1 depicts the study selection procedure, which followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) standards (Shamseer et al., 2015). Table 1 provides a summary of reinforcement measures returned in the search query. Table A.1 in Appendix A summarizes all studies included in the review. Copies of all measures, including scoring instructions, are outlined in Appendix B.

4.2. Reinforcement surveys

The search yielded 32 studies using reinforcement surveys (Pleasant Events Schedule and Adolescent Reinforcement Survey Schedule) to assess substance-related and substance-free reinforcement. Reinforcement surveys are self-report behavioral inventories of two widely accepted parameters of reinforcement: the amount of time spent engaged in the activity and the subjective enjoyment of the experience. Research suggests that these two facets of reinforcement (i.e., enjoyment and frequency) may be divergent (Magidson, Robustelli, Seitz-Brown, & Whisman, 2016; Murphy, Barnett, Goldstein, & Colby, 2007), although both are theoretically relevant to understanding choice behavior. Both concepts are variations of important factors of reinforcement commonly studied in basic research, namely reinforcement magnitude (i.e., strength of the reinforcer; Davison & Baum, 2003; Young, 1981) and frequency (i.e., rate of reward receipt; Davison & Baum, 2000; Schneider, 1973) Reinforcement surveys have been used in the assessment and treatment of a wide range of disorders, including depression (Lejuez, Hopko, & Hopko, 2001), anxiety (Bouman & Luteijn, 1986), Alzheimer's disease (Amspoker et al., 2017) and substance use (Daughters et al., 2018).

Correia and colleagues (Correia, Carey, Simons, & Borsari, 2003; Correia, Simons, Carey, & Borsari, 1998) first modified reinforcement surveys for a series of studies designed to assess the relationship between alcohol use and the amount of reinforcement derived from both substance-related and substance-free activities. Substance-related and substance-free reinforcement were differentiated by having participants complete two sets of frequency and enjoyment ratings for each activity—one for instances when the activity occurred while drinking or using drugs (substance-related reinforcement) and one for instances that occurred when the participant had not been drinking or using drugs (substance-free reinforcement). Frequency and enjoyment ratings are multiplied together to create substance-free and substance-related cross-products. Next, a reinforcement ratio can be calculated by dividing the substance-related cross-product by the total reinforcement score (substance-related + substance-free), accounting for substance-free reinforcement.

The 320 item Pleasant Events Schedule (PES; MacPhillamy & Lewinsohn, 1982) has demonstrated adequate test-retest reliability and concurrent and predictive evidence of validity. The PES has proven useful as a means of monitoring the reinforcing activities of depressed patients participating in behavior therapy (Lewinsohn, Sullivan, Grosscup, & J., 1980), and evidence suggests it also accurately predicts future behavior (summarized in MacPhillamy & Lewinsohn, 1982). The Adolescent Reinforcement Survey Schedule (ARSS; Holmes, Heckel, Chestnut, Harris, & Cautela, 1987; Holmes, Sakano, Cautela, & Holmes,

Table 1
Summary of self-report measures of reward and reinforcement.

	Sample item	Item Quantity	Substance-free and Substance-related?	Key Citation	Scoring
Adolescent Reinforcement Survey Schedule	How often did you go out to eat with friends? How enjoyable was it?	32–54	Yes	Murphy et al., 2005	Frequency multiplied by enjoyment (substance-free and substance-related); cross product of substance-related divided by total reinforcement
Modified Pleasant Events Schedule	How often have you watched TV? How pleasant was it?	42–320	Yes	Correia et al., 1998	Frequency multiplied by enjoyment, separated by substance-relatedness; substance-related divided by total reinforcement
Alcohol-Savings Discretionary Expenditure	–	N/A	Yes	Tucker et al., 2002	Alcohol expenditure divided by total expenditure
Pleasant Images	–	10	Yes	Meshesha et al., 2017	Average scores for pleasant images
Time Allocation	How many hours in the past week have you spent obtaining, using, and recovering from alcohol?	N/A	Yes	Meshesha et al., 2015	Alcohol/substance-related time allocation divided by total time allocation
Reward Probability Index	A lot of activities in my life are pleasurable	20	No	Carvalho et al., 2011	Total score
Environmental Reward Observation Scale	There are many activities that I find satisfying.	10	No	Armento & Hopko, 2007	Total score
Modified Timeline Follow Back	–	7	Yes	Murphy et al., 2006	Drinking and nondrinking days selected; Participants identify activities and report enjoyment

1991) is another well-validated assessment tool that has been widely used in research on substance use among teens and young adults. The ARSS includes 45-items that are primarily social in nature (e.g., dating, peer and family interactions). Psychometric evaluation has established the test-retest reliability and concurrent validity of the measure in a college sample (Hallgren, Greenfield, & Ladd, 2016).

4.2.1. Literature review of reinforcement survey studies

In a study with college undergraduates, Correia et al. (1998) observed a negative relationship between substance-free reinforcement (obtained with the PES) and the frequency of substance use. Further, the ratio of substance-related to total reinforcement (reinforcement ratio) accounted for additional unique variance. Van Etten, Higgins, Budney, and Badger (1998) found that cocaine abusers reported a lower frequency of engagement in, but not enjoyment of, non-social, introverted, passive outdoor and mood-related activities relative to the control group. Intravenous cocaine use and prior treatment for cocaine abuse predicted particularly low frequency of pleasant events. Subsequent analyses extended these findings cross-sectionally to new populations, such as substance-using psychiatric outpatients (Correia & Carey, 1999), and to other outcomes, such as with measures of substance use quantity and related negative consequences (Correia, Carey, & Borsari, 2002), demonstrating the generalizability of the reinforcement surveys.

One large prospective study found that depression negatively predicted substance-free reinforcement (measured with PES), which in turn negatively predicted smoking behavior over four years in a young adult sample (Audrain-McGovern, Rodriguez, Rodgers, & Cuevas, 2010). Deficits in substance-free reinforcement might also contribute to socioeconomic disparities in patterns of substance use among high school students: the relationships between substance use and risk factors such as lower levels of parental education and increased incidence of conduct problems are mediated by decreased engagement in substance-free reinforcing activities (Andrabi, Leventhal, & Khoddam, 2017), findings that have also been replicated longitudinally (Andrabi, Khoddam, & Leventhal, 2017; Khoddam, Cho, Jackson, & Leventhal, 2018).

A number of studies have found associations between the ARSS-SUV and substance use among college student drinkers. These studies demonstrate positive associations between the reinforcement ratio and typical drinks per week and related problems (Delmée, Roozen, & Steenhuis, 2017; Murphy, MacKillop, Skidmore, & Pederson, 2009; Skidmore, Murphy, & Martens, 2014), and negative associations between substance-free reinforcement and past month binge drinking episodes and number of drugs used within the past month (Meshesha, Dennhardt, & Murphy, 2015; Skidmore & Murphy, 2010). In fact, a recent behavioral economic analysis found that the ARSS reinforcement ratio was the strongest predictor of alcohol consumption and problems in a structural regression model that included demographic variables, delay discounting, and alcohol demand (Acuff, Soltis, et al., 2018). Substance-free reinforcement may be protective against alcohol problems in part due to its association with protective behavioral strategies (Voss, Soltis, Dennhardt, Martens, & Murphy, 2018). The utility of the ARSS has also been demonstrated among more general community samples of adult drinkers (Morris et al., 2017), enhancing confidence in generalizability.

4.2.1.1. Reinforcement surveys as a measure of treatment response. The ARSS-SUV is also a useful predictor of whether individuals are likely to response favorably to an alcohol intervention. Murphy, Correia, Colby, and Vuchinich (2005) found that greater baseline reinforcement ratio predicted greater drinking six-months after a brief alcohol intervention. Another study replicated this finding and also found that baseline levels of the reinforcement ratio predicts change in marijuana use (Dennhardt, Yurasek, & Murphy, 2015). Further, individuals who show significant reductions in drinking in the months following an intervention also

show simultaneous reductions in the reinforcement ratio and increases in substance-free reinforcement associated with academic activities (Murphy et al., 2005).

This research led to the development of a behavioral economic supplement to brief alcohol interventions that is designed to increase future orientation and engagement in constructive alternatives to drinking. Both an initial pilot study (Murphy et al., 2012) and a randomized controlled trial (Murphy, Dennhardt, et al., 2012) demonstrated that the addition of the behavioral economic supplement to an established brief intervention lead to decreases in alcohol use and, in the case of the controlled trial, outperforms a brief intervention supplemented with relaxation training. The intervention was particularly effective, relative to control, for heavy drinkers with symptoms of depression or lower levels of substance-free reinforcement, suggesting that the supplement can be used to target students with a specific pattern of behavior previously identified as a risk factor for substance use.

It is also notable that increases in engagement in substance-free activities was associated with increases in abstinence from drug use during a trial of contingency management for methadone-maintained cocaine abusers (Rogers et al., 2008). This is also the case among trials focused on smoking cessation: smokers who increased substance-free reinforcement (using the PES) during a smoking cessation trial were twice as likely to quit smoking at the end of treatment (Audrain-McGovern et al., 2009; Schnoll et al., 2016).

4.2.1.2. Moderators of the relationship between reinforcement surveys and substance misuse. Several important moderators have been examined in the relationship between alternative reinforcement and substance use, including gender and family substance use history. Across studies, women tend to have higher substance-free reinforcement and lower reinforcement ratios compared to men (Morris et al., 2017; Murphy, Correia, & Barnett, 2007; Skidmore et al., 2014; Skidmore & Murphy, 2010). However, moderation effects in the relationship between the reinforcement indices and substance use are less consistent. One study found a negative association between substance-free activity enjoyment and past-month alcohol use among women, but not for men (Murphy, Barnett, et al., 2007). Similarly, the reinforcement ratio is significantly associated with alcohol-related problems for women, but not men (Skidmore et al., 2014). Gender may also influence intervention effects: one study demonstrated that women with a smaller reinforcement ratio at baseline were more likely to report lower drinking 6-months later, an effect that was not present for men (Murphy et al., 2005). However, other studies have not found the moderation effect by gender (Skidmore & Murphy, 2010). The studies demonstrating a mediational effect of substance-free reinforcement in the relationship between risk factors (i.e., conduct problems and SES) and substance problems also did not find differential results based on gender (Andrabi, Khoddam, & Leventhal, 2017; Khoddam et al., 2018; Lee et al., 2018). More research should be done in an attempt to solidify the existence of a gender effect, if any.

Research on other potential moderating variables is sparse. One study examined the moderating effect of a proxy for genetic variance (i.e., family history of problematic substance use) in the relationship between substance-free reinforcement and alcohol problems among college students. The results suggest that substance-free reinforcement is negatively associated with alcohol problems for those with a positive family history of alcohol abuse but not for those without this family history (Joyner, Acuff, Meshesha, Patrick, & Murphy, 2018). Finally, Lee et al. (2018) found that socioeconomic status did not moderate the mediating effects of substance-free reinforcement on the relation between conduct problems and substance use.

4.2.1.3. Strengths, limitations, and future directions of the reinforcement survey approach. Reinforcement surveys demonstrate strong psychometric properties, robust relations across various forms of drug use, and can be used to inform treatment planning (e.g., to provide feedback on reinforcement ratio and to identify potential alternatives to drinking) and as a secondary treatment outcome variable. However, reinforcement surveys also rely on retrospective self-report and require participants to make aggregate ratings of recent participation and enjoyment rather than asking about specific events. Another significant limitation is that these indices include a predetermined list of activities and do not allow for the ideographic identification of potentially rewarding activities. Some researchers have used timeline follow-back approaches to obtain information about specific recent substance-related and substance-free activities, an approach that allows for the collection of additional contextual information. For example, Murphy, Barnett, and Colby (2006) asked college student drinkers to provide information about recent evening activities that either included drinking or were substance-free. Overall activity enjoyment level was positively associated with the number of drinks consumed, and the number of peers present was actually a stronger predictor of enjoyment (across drinking and non-drinking evenings). The study identified a number of specific substance-free evening activities that were as enjoyable as drinking occasions (e.g., attending theatre, playing sports, eating at restaurants). Additionally, higher average enjoyment ratings for substance-free evening activities was associated with lower drinking among women, and greater motivation to change drinking among men and women (Murphy, Barnett, et al., 2007). Similar information can be obtained prospectively using ecological momentary assessment (EMA), which allows for the collection of real-time data on activity, mood, cognitions, and a range of other variables (e.g., physiological markers of activity, global positioning data; see review by Bertz, Epstein, & Preston, 2017). The increasing availability of smart devices and wearable technology (Kumar et al., 2013) will likely lead to significant advances in our ability to collect data on important aspects of activity and reinforcement without relying on retrospective self-report.

It is also worth noting that both the PES and the ARSS assess the frequency and pleasure of activities but do not consider other key parameters of reinforcement that have been shown to influence choice behavior, including delivery schedule, quality, magnitude, and delay (Herrnstein, 1970). Developing a survey that accounts for reinforcer delay may be an especially important factor to incorporate given the consistently reported relationship between engagement in addictive behaviors and a preference for immediate over delayed reinforcers (Bickel et al., 2014). The frequency and enjoyment ratings also have limitations; frequency does not adequately assess total duration of engagement, and self-reported enjoyment may differ between individuals. Further, activities have the potential to be reinforcing without accompaniment of the subjective feeling of enjoyment (e.g., parenting, academic activities, arduous physical activity), and original clinical formulations of reinforcement assessed sense of enjoyment and accomplishment (Beck & Greenberg, 1984), which is not assessed with current iterations. Other factors, such as frustration tolerance (Harrington, 2011), may impact “accomplishment” aspects of reinforcement, in addition to recovery potential, but have not been adequately examined. Another limitation of these surveys is that certain activities may occur simultaneously, which increases measurement error of the reinforcement ratio. Further, simultaneous engagement in some activities, such as watching a movie while hanging out with friends (rather than alone) may result in greater quality of reinforcement that is multiplicative by nature and not currently captured with reinforcement surveys.

The ARSS-SUV is not appropriate for use among middle-aged or older adult populations due to items specific to the adolescent/young adult population. Additionally, like the PES the items are over 30 years old and thus do not capture many modern activities such as engaging with social media or video games. However, the general reinforcement survey approach is well validated (Correia et al., 2002; Hallgren et al., 2016; Lewinsohn, 1974; Lewinsohn et al., 1980), and items specific to a

given population could reasonably be administered alongside a battery of standard items common to all or most populations. Subsequent studies using both qualitative and quantitative approaches to measurement development could likely produce a survey that is 1) updated and 2) sufficiently comprehensive in terms of the number of items and reinforcement parameters assessed without placing an undue burden on participants. This could result in ideographic approaches, such as timeline follow backs or EMA, or in approaches assessing general categories of behavior (e.g., how often do you socialize without alcohol, and how enjoyable is that typically?) rather than each individual potential activity.

4.3. Measures of resource allocation

4.3.1. Alcohol savings discretionary expenditure

Another measurement method grounded in behavioral theories of choice uses relative actual allocation of monetary resources to various domains as an indicator of relative reinforcement. The search yielded 11 studies that used the Alcohol Savings Discretionary Expenditure (ASDE) or a similar approach in substance misusing populations. Tucker and colleagues reasoned that, for those with fixed recurring expenditures and discretionary income, the spending pattern of discretionary funds on alcohol, versus savings, would reflect their relative degree of preference for alcohol compared to the delayed reward of savings (Tucker, Roth, Vignolo, & Westfall, 2009). The original ASDE requires a careful interview with a participant, who often brings financial records, to determine the amount of money spent on alcohol or put into savings in the period of time before an attempt to stop or reduce drinking. The ASDE outcome is the ratio of discretionary money spent on alcohol versus savings.

4.3.1.1. Literature review of ASDE studies. A number of studies have utilized the ASDE to measure relative reinforcement value of alcohol in middle-class adult problem drinkers who were attempting to resolve an alcohol problem without formal treatment. These studies have shown that greater allocation to savings is related to greater abstinence or moderation outcomes and more stable resolutions (Tucker et al., 2009; Tucker, Foushee, & Black, 2008; Tucker, Foushee, Black, & Roth, 2007; Tucker, Vuchinich, Black, & Rippens, 2006; Tucker, Vuchinich, & Rippens, 2002; Tucker, Cheong, Chandler, Lambert, Kwok et al., 2016). Another study found that higher ASDE was related to greater consumption and alcohol-related problems among community high-risk drinkers who had achieved abstinence or low-risk drinking for at least three weeks without undergoing treatment (Tucker, Cheong, Chandler, Lambert, Pietrzak et al., 2016).

Several studies used an abbreviated version of the ASDE by dividing past-month drug and alcohol expenditures by total past-month discretionary income estimates. In these studies, the ASDE was significantly associated with drinks per week, but not alcohol-related problems (Murphy et al., 2015, 2009; Skidmore et al., 2014). Further, ASDE was associated with other indices of alcohol valuation, supporting the construct validity of the measure. Other studies have used ASDE as a predictive index of change in behavior following an intervention. For example, proportionate discretionary income towards opioids relative to savings predicts a greater likelihood of opioid use during treatment (Worley, Shoptaw, Bickel, & Ling, 2015). Further, change in ASDE from baseline to the 6-month follow-up after receipt of a brief intervention predicted drinking outcomes among college students (Murphy et al., 2015).

4.3.1.2. Strengths, limitations, and future directions of the ASDE measurement approach. The ASDE has several strengths as an index of proportionate reinforcement from alcohol relative to a delayed substance-free reward. It is an ecologically valid and objective measure of actual resource allocation to alcohol relative to an easily quantifiable, and delayed, alternative reward. Thus, the measure also reflects intertemporal decision making (delay discounting), which is a robust risk factor for substance abuse (Bickel et al., 2014). These studies suggest that the ASDE provides a valid index of measuring the relative value of alcohol versus delayed alternative rewards in middle -class community samples but may need to be modified for samples that do not regularly allocate money to savings, such as with low SES samples. Low SES samples may struggle to pay their monthly bills and may be less likely to be able to contribute to savings in the way that middle and higher SES samples can. Further, many students and young adults do not have a steady income and therefore do not have funds available to allocate to a savings or a large number of discretionary activities. The briefer ASDE that asks about money spent on alcohol relative to all discretionary expenditures may be most appropriate for samples that do not allocate money to savings. Another issue with the ASDE is the participant burden and potential for inaccuracy. Individuals, especially heavy drinkers, may not be able to recall exactly how much they have spent on alcohol or drugs. The common use of smart phones to access bank information may help remedy this issue and allow participants to look up expenditures, although not everyone may have access to this information or may utilize cash to purchase substances. Finally, the ASDE does not identify specific activities, and therefore may be less useful for specific treatment planning compared to reinforcement surveys.

4.3.2. Time allocation

Given that time is a finite and “zero sum” resource for all, the amount of time allocated to one activity relative to others or expressed as a proportion of total time in a week or day is an intuitive and objective measure of reinforcing value (Baum & Rachlin, 1969; Herrnstein, 1970). Research suggests there may be specific categories of substance-free activities that are protective against substance use. For example, time spent in academic, athletic, religious, and service-related activities is associated with lower rates of substance use and binge drinking among college students (Fenzel, 2005; Meshesha et al., 2015; Vaughan, Corbin, & Fromme, 2009; Wechsler, Davenport, Dowdall, Grossman, & Zanakos, 1997). Despite the theoretical efficacy of time allocation to measure reinforcement, few studies to date have done so using brief, self-report measurement. The search yielded four studies utilizing time allocation as a measure of reinforcement and substance use in a sample of college students. These three studies measured time allocation by asking students to estimate the total number of hours spent in various activities during a typical week in the past month. Activities queried included: a) time spent in class, b) time spent doing homework, c) participating in social fraternity or sorority activities, d) participating in other university organizations, e) internship or volunteer activity related to major or potential career, f) paid employment, g) exercise or sports, h) time with family, i) religious activity, j) drinking, k) using drugs, and l) time spent using the internet for non-academic purposes (e.g. social media).

4.3.2.1. Literature review of time allocation studies. Meshesha et al. (2015) examined group differences in time allocation between heavy drinkers, heavy drinkers who also used marijuana, and heavy drinkers who used marijuana and other illicit drugs (polysubstance users). They found that polysubstance users reported significantly less time allocated to exercise, extracurricular, and academics compared those who were heavy drinkers but did not use other drugs. Further, individuals who reported heavy drinking and marijuana use reported less exercise and school activity compared to heavy drinkers who did not use marijuana. Another study found similar results, suggesting that any drug use is associated with less engagement in academics and exercise (Meshesha, Utzelmann, Dennhardt, & Murphy, 2018). Further, Meshesha, Pickover, Teeters, and Murphy (2017) found that compared to no drug use, non-medical prescription opioid use was associated with less time allocated to academic activities including completing homework, attending classes, and participating in extracurricular activities among college

students over a 12-month period. Time allocated to these academic activities did not, however, predict change in opioid, marijuana or alcohol use prospectively. A final study examined factors that might predict time devoted to academic activities (Acuff et al., 2017) among the context of heavy drinking college students and found that future valuation variables predicted time devoted to academics among heavy drinkers, demonstrating the utility of these measures in capturing the experience of reinforcement among other activities, as well.

4.3.2.2. Strengths, limitations, and future directions of the time allocation measurement approach. Although only a few studies have used this measurement approach, these findings suggest that time allocation may be a useful method of measuring reinforcement in substance use research. The time allocation method is straightforward and face valid, is consistent with behavioral economic theory, and has the potential to be very precise if an ecological momentary assessment approach is utilized. One limitation of this method is that a select number of activities are measured, and there may be important categories of activities to which people allocate their time that are missing. Additionally, although specific time use categories have been negatively associated with drug use, there is no single index that reflects proportionate reinforcement from substance use relative to alternatives, and time use variables have not shown the predictive validity that reinforcer survey or ASDE approaches have. Further, humans are typically poor at recall and time tracking (Eisenhower, Mathiowetz, & Morganstein, 1991; Shiffman et al., 1997), and the sum of time represented in the time allocation measure is often not equal to the number of hours in a week. To solve this issue, some studies have used a percentage approach in which time allocation towards a given activity is considered relative to all time reported in any activity (Meshesha et al., 2018). Future research should use EMA-based approaches to facilitate prospective monitoring of time allocation.

Another limitation of this method is that not all of these activities are mutually exclusive. That is, many people watch TV or hang out with friends at the same time they are engaging in drinking or drug use. A further helpful distinction may differentiate between time allocation to obligatory v. discretionary activities, as other methods (i.e., ASDE reviewed above) suggest that the valuation of substance use may be best gauged by examining relative discretionary time allocation. The time allocation approach might be especially appealing for behavioral addictions that require engagement in a single activity, rather than using a substance simultaneously within the context of other activities. Finally, the time allocation approach does not assess the subjective valence of the activity, which may be an important component for understanding behavioral reinforcement. Indeed, associations between the time allocation measure and substance use have generally been weaker than those with other measures of reinforcement, which may be due to both measurement/recall error and the failure to integrate the subjective appraisal of the activity valence.

4.3.3. Rating scale measures of reward

The search yielded eight studies utilizing Likert scale measurement approaches to capture reward experience within the context of substance misuse. The most commonly used scales were the Environmental Reward Observation Scale (EROS; Armento & Hopko, 2007) and the Reward Probability Index (RPI; Carvalho et al., 2011). Both scales were developed to measure response-contingent positive reinforcement (i.e., the increase in frequency of a behavior due to the presentation of a reinforcer), a concept central to depression research and treatment (Boswell et al., 2017). The EROS, developed first, is a 10-item Likert scale specifically assessing self-observed environmental reward. The RPI, a 20-item Likert scale questionnaire, include two factors – environmental suppressors (the availability of rewarding opportunities within one's environment) and reward probability (ability to experience reward; Carvalho et al., 2011). Initial validity studies showed that scores on the RPI were strongly associated with daily diary reports of activity engagement and enjoyment among undergraduate students (Carvalho et al., 2011).

4.3.3.1. Literature review of rating scale studies. Three studies have utilized Likert scale measurement methods to examine the association between substance use and response-contingent positive reinforcement. In a cross-sectional sample of 393 heavy drinking college students, Joyner et al. (2016) found that the environmental suppressor subscale of the RPI, but not the reward probability subscale, predicted both alcohol use disorder and alcohol-related problems after controlling for depression, alcohol consumption, gender, and age. The second paper used the RPI to explore the role of reward in the comorbidity of posttraumatic stress and alcohol use (Acuff et al., 2018). In a sample of college students who reported alcohol use (n = 203), the authors found that the environmental suppressor subscale of the RPI, but not the reward probability subscale, cross-sectionally mediated the relation between posttraumatic stress symptom severity score (measured with the PCL-5; Weathers et al., 2013) and alcohol-related problems and alcohol craving. In the third study, Meshesha et al. (2018) found that heavy drinkers who also reported polysubstance use reported lower reward experience and environmental reward (using the RPI) compared to heavy drinkers who were not polysubstance users. These studies suggest that low levels of environmental reward are associated with alcohol problems and polysubstance use among college students. However, college student problem drinkers and drug users may have an intact ability to experience reward if it is available. The lack of ability to experience pleasure likely develops over the course of substance misuse and may play a more prominent role in more severe populations (Lubman, Allen, Peters, & Deakin, 2008).

The remaining RPI or EROS studies (n = 4) use the measures as outcomes in treatment studies for illicit drugs (non-specific) or cigarette smoking. Two studies examined the influence of a supplemental, brief behavioral therapy for depression, the Life Enhancement Treatment for Substance Use (LETS Act), on EROS scores (Daughters et al., 2008). LETS Act is a brief behavioral activation treatment delivered in six sessions over two weeks (approximately 4.5 hours of contact time). In the first study (Daughters et al., 2008), 44 individuals receiving inpatient services for illicit drug use (also reporting depression) were randomized to either treatment as usual (TAU) or TAU with the supplemental LETS Act sessions. The authors found that participants in the TAU + LETS Act condition reported significantly greater EROS scores at posttreatment and two-week follow-up compared to those in the TAU alone group. A second study compared the effect of LETS Act intervention alone with a contact-time matched control, supportive counseling (SC), in increasing environmental reward activation (Magidson et al., 2011). Fifty-eight individuals in residential treatment for illicit drug use were randomized into five, 1-hour sessions over two weeks of either LETS Act or SC. In this study, there was no difference between LETS Act or SC in EROS scores from pre to posttreatment. Finally, two studies used the EROS or RPI to measure environmental reward as an outcome of behavioral activation treatment for smoking cessation. In both a sample of young adult smokers (MacPherson, Collado, Ninnemann, & Hoffman, 2017) and a sample of adult smokers (Macpherson et al., 2011), there were no significant differences in environmental reward in the behavioral activation treatment condition versus the treatment as usual condition.

4.3.3.2. Strengths, limitations, and future directions of the rating scale measurement approach. The EROS and RPI have several strengths, including that the measures are very brief, possess strong psychometric properties, can be useful for treatment planning, and have shown associations with treatment response. However, the Likert scale measurement method relies largely on the individual's cognitive awareness of their experience of reward, and it is possible that behavioral change predates cognitive and emotional awareness. People are also sometimes inaccurate reporters of their own behavior,

limiting the utility of self-report measures. These measures do not explicitly specify whether the items are substance-free, and they do not identify specific activities. Therefore, they may be less useful for specific treatment planning or to identify specific activity categories that might be inversely related to substance use. Further, the RPI and the EROS have only been compared to each other and a measure of depression to establish concurrent validity. Meshesha et al. (2018) reported a significant association between time spent exercising and both RPI subscales, and time spent in academics and the RPI total. We also examined relations between RPI subscales and ARSS indices from an unpublished dataset and found that the RPI reward probability subscale was positively associated with substance-free ($r = 0.45$; $p < .001$) and substance -related reinforcement ($r = 0.10$; $p = .03$), but negatively associated with the proportionate substance-related reinforcement variable (reinforcement ratio; $r = -0.17$; $p = .001$). The RPI environmental suppressors subscale was not related to substance-related reinforcement but was significantly associated with substance-free reinforcement ($r = 0.15$; $p = .004$) and the reinforcement ratio ($r = -0.18$; $p < .001$). Future work should continue to establish the construct validity of the items. The measures could be further enhanced by explicitly inquiring about various primary categories of reward (e.g., substance-related, physical activity, work, social activity, leisure activities/hobbies). This would more cleanly demarcate the availability of reward versus the experience of reward, and the specificity might enhance the measure's clinical and predictive utility.

4.3.4. Other

Another measurement approach attempts to measure hedonic response to pleasant images by combining Likert scale measurement with behavioral paradigms modeled after electrophysiology research. Meshesha et al. (2017) presented a series of pleasant images to college students reporting opioid misuse or controls (no past year drug use), who were asked to rate them on a scale of 0 to 10. Pictures were taken from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1997) and were images of money, nature, and fireworks. This measure, along with demographic information and alcohol and drug use, was also collected 6- and 12-months following the initial assessment. Those reporting past-year opioid misuse rated substance-free images as less pleasant than those in the control group, an effect that lasted through the 12-month follow-up. Further, opioid users who reported greater hedonic response to the substance-free pleasant images were less likely to consume alcohol at the 12-month follow-up. The design and findings of this study are consistent with previous research using electroencephalography (EEG) to understand reward response (Lubman et al., 2009), suggesting that this may be a feasible way to capture reward experience without the cost of EEG equipment, although this has not been adequately studied.

The pleasant image task described above may be an alternative measurement approach that avoids the errors implicit in face valid measures of reward experience. On the other hand, there may be some question as to the validity of this measure in the substance-using population and the applicability of these ratings to reinforcement derived from actual activities. Although initial findings are encouraging, it is important to utilize this measure among other populations. Another limitation is that responses on this task provide one narrow index of the ability to experience aesthetic reward that may not generalize to the experience of other facets of reward or does not address reward availability. Further, the pleasant images task should be validated against electrophysiological measures of reward using similar paradigms (e.g., oddball tasks; Bartholow, Lust, & Tragesser, 2010). Finally, the stability of this measurement method is unclear. Although the findings from the above studies suggest strong predictive utility (Meshesha et al., 2017), test-retest reliability of the pleasant images task has not been established. The pleasant images task may capture the same construct measured by electrophysiological indices of reward, which demonstrate robust stability over time (Levinson, Speed, Infantolino, & Hajcak, 2017; Segalowitz & Barnes, 1993). Establishing this stability is a research priority, considering that it may be an inexpensive measurement method paralleling electrophysiological measurement of event-related potentials (e.g., P3).

5. Summary, clinical applications, and future directions

Substance-free reinforcement and reward are important theoretical constructs in understanding the etiology and maintenance of substance addiction, and a variety of measures have been designed for this specific purpose. Findings using these measures demonstrate robust relations between substance-free reinforcement and substance misuse across samples, substances, and over time, highlighting the utility of these constructs in elucidating the phenomena of addiction. The measurement methods summarized here may also have clinical implications for treatment and intervention approaches that are conceptually based in reinforcement. First, they may provide indices of problem severity that are not redundant with existing severity assessment approaches, which typically focus on quantity and frequency of drinking and the associated problems (Tucker et al., 2016, 2002). Further, these measures may serve as useful tools during the process of treatment of substance use and addiction. Both reinforcement surveys, originally formulated within the context of depression treatment, and time allocation measures may be useful in identifying substance-free activities available in the environment that may serve as substitutes. The measures may also serve as useful elements in feedback interventions (Miller et al., 2013; Neighbors et al., 2010). The time allocation measure provides a quantifiable index that can be displayed in the form of a figure to create conversation about current activity engagement and its influence on choices to engage in substance use (Murphy, Dennhardt, et al., 2012). Reinforcement surveys in particular provide information about enjoyment, which could assist therapists in identifying activities that are enjoyable, yet are infrequently engaged in, as activities to bolster against continued substance use (Magidson et al., 2011; Meyers et al., 2011; Murphy, Skidmore, et al., 2012). Finally, these measures may provide indices of treatment progress and outcomes. The ASDE scale predicts drinking behavior over time and may be a useful monitor for ongoing changes in reinforcement. Likert scale measurements, too, may be most useful for weekly tracking of the enjoyability or pleasurable aspects of reinforcement.

Our review highlights the promise of efforts to accurately capture substance-free reinforcement in both clinical and research settings and suggests future research directions. First, research should attempt to increase the content validity of measures to increase confidence and decrease measurement error. The measures reviewed above are not comprehensive in their assessment; further, the extent to which it is important to comprehensively measure all activities versus a subset of activities is unknown (i.e., activities with functional relations with substance use; academics, social activities, exercise, etc.). The importance of differentiating between reward availability and the decision to engage is also unknown, as is the operationalization of discretionary versus mandatory time or resource expenditure, two topics relevant for understanding the appropriate content explicit within each measure.

Second, although strong relations have been established with substance use and other relevant self-report methods, there is a need to establish convergent validity in a multimethod framework (Campbell & Fiske, 1959). There is increasing interest in understanding psychopathology from a dimensional approach, identifying underlying constructs that are responsible for the etiology of psychiatric disorders. These self-report measures might represent subconstructs in the positive valence system of the Research Domain Criteria (RDoC) matrix

(i.e., research framework for mental disorders; Cuthbert & Insel, 2013), and should be systematically compared to other units of analysis within each subconstruct to clarify the exact nature of each measure. Thus, future research should extend the validity of each of these measures by comparing with indices of reinforcement and reward derived from neuroimaging and electrophysiological techniques. A large amount of research has identified electrophysiological biomarkers of response to rewarding stimuli using event-related potentials (i.e., P3 and RewP; Kamarajan et al., 2010; Petit, Kornreich, Dan, Verbanck, & Campanella, 2014; Proudfit, 2015). Other biological (i.e., eye tracking; Marks, Pike, Stoops, & Rush, 2015) and behavioral (i.e., choice tasks; Field et al., 2016; Hardy, Parker, Hartley & Hogarth, 2018; Moeller et al., 2013) techniques for assessing attention, motivation, and reward have also been linked to substance use. Linking these two separate lines of research could provide concurrent validity for both, and strong relations between self-report measures of reward and reinforcement and neurological or behavioral indices could suggest inexpensive measurement alternatives to neuroimaging for use in larger population and clinical samples where laboratory assessment would not be feasible.

Finally, many questions still exist regarding the relation between substance use and substance-free activities. For example, although the research summarized here generally supports an inverse relation between substance use and substance-free reinforcement, research has suggested that nicotine and alcohol can enhance the experience of substance-free reward, even when the individual is not engaging with the substance (Murphy et al., 2005; Perkins, Karelitz, & Boldry, 2017), and it is possible that decisions to use drugs are more related to the possibility of increases in total reward, or to day-to-day fluctuations in substance-free reward, than to the absolute amount of substance-free reward. Prospective research that explicates the dynamic associations between drug use and levels of substance-related, substance-free, and total reinforcement over time is necessary to further refine these theoretical models and associated measurement approaches. Further, some research has identified gender differences in substance-free reinforcement (Skidmore & Murphy, 2010), and other moderators may exist that could further inform personalized treatment for substance use disorders. Indeed, our review highlighted a number of moderators (e.g., family history of problematic substance use; gender) that have been examined with reinforcement surveys, but no moderation analyses exist with any of the other measures of reinforcement or reward. This body of literature is also largely disconnected from literature examining certain protective factors such as religiosity or strong cultural identity (Greenfield et al., 2018), mindfulness (Hochster, Block-Lerner, Marks, & Erblich, 2018), and exercise (Brown et al., 2014), all which represent a set of cognitions or behaviors related to engagement in substance-free activities that could be bolstered to decrease overall substance-related reinforcement.

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Contributors

SFA and JGM developed the research study and wrote the search protocol. SFA and AAD conducted literature searches and data coding. SFA, AAD, and CJC wrote the first draft of the paper. All authors contributed to editing and have approved of the final manuscript.

Conflicts of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cpr.2019.04.003.

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