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Quantifying Reinforcement Value and Demand for Psychoactive Substances in Humans

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Abstract

Behavioral economics is an emerging cross-disciplinary field that is providing an exciting new contextual framework for researchers to study addictive processes. New initiatives to study addiction under a behavioral economic rubric have yielded variable terminology and differing methods and theoretical approaches that are consistent with the multidimensional nature of addiction. The present article is intended to provide an integrative overview of the behavioral economic nomenclature and to describe relevant theoretical models, principles and concepts. Additionally, we present measures derived from behavioral economic theories that quantify demand for substances and assess decision making processes surrounding substance use. The sensitivity of these measures to different contextual elements (e.g., drug use status, acute drug effects, deprivation) is also addressed. The review concludes with discussion of the validity of these approaches and their potential for clinical application and highlights areas that warrant further research. Overall, behavioral economics offers a compelling framework to help explicate complex addictive processes and it is likely to provide a translational platform for clinical intervention.

Keywords

Addiction; Alcohol; Behavioral Economics; Delay Discounting; Demand; Drugs; Impulsivity; Nicotine; Reinforcement

Introduction

Drug addiction is one of the most recalcitrant and devastating afflictions of the human condition. Despite years of research, addiction remains a perplexing behavioral phenomenon and the available treatments are limited. Drug abuse treatments are largely based on the conceptualization that humans are rational agents, hard-wired to make decisions based on available information concerning the future consequences [e.g., 1]. Yet, once in the throes of addiction, an individual makes the choice to use a substance despite the knowledge that this choice will likely lead to negative outcomes (e.g., job loss, strained relationships, poor health). Indeed, despite ample first-hand experience with these causal relationships, the

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affected individual continues to make the same costly choice even in light of the known negative consequences. Although on the face of it, such drug-seeking behavior is irrational and incompatible with our understanding of human behavior, researchers have begun to make sense of pathological consumption patterns under a behavioral economics lens.

Behavioral economics is defined broadly here, as the attempt to predict how individuals allocate limited resources (e.g., costs: money, time, effort) to obtain a commodity, under varying environmental constraints (e.g., price, availability), [e.g., 2]. Behavioral economics brings together psychological and economic principles, based on the idea that organisms engage in behaviors because there is an expected utility or a reinforcing value to doing so (e.g., in humans, that drinking alcohol will relieve negative affect). Importantly, each decision has an associated cost in terms of consequences [e.g., 3], but this cost is subjectively appraised and can differ widely across individuals and circumstances. In other words, the reinforcing value of substances and the choices that stem from these valuations depend greatly on the individual and the context. When applied to addictive behaviors, behavioral economics offers a rich opportunity to investigate dynamic variations in the reinforcing value of drugs and associated choice behaviors.

A core concept in addiction is that a progressive change in decision-making occurs with regard to the psychoactive substance of interest. That is, as experience with a substance mounts, the individual appears to lose control over use and engage in the apparently irrational behavior of using a substance despite growing costs. In behavioral economic terms, the relative reinforcement of a substance becomes disproportionately high compared to other options [e.g., 2, 4]. How do these decision-making processes change across the trajectory of substance use, from early experimentation through regular controlled use and to full-blown dependence? Identifying these processes may help develop and inform effective treatment strategies. Here, we will review the theories and methods used in these behavioral economic analyses of substance use, and highlight some of the advances that have resulted. Although many behavioral economic principles have been developed and extensively applied in nonhuman research [e.g., 5, 6–8], we will focus only on methods used in studies with humans.

Objectives

1) Present the behavioral economic nomenclature

2) Describe behavioral economic models and concepts used in substance use research

3) Review measures and tasks derived from those theoretical models, including those with real and hypothetical rewards.

4) Examine sensitivity of behavioral economic tasks to variables related to drug use (e.g., duration of drug experience, current drug use status, acute administration and deprivation).

5) Evaluate the overall utility of these tools and their potential clinical implications

6) Suggest areas of future research

I. Behavioral Economic Nomenclature

The below table (Table 1) provides definitions of terms used in behavioral economics and in this paper.

II. Behavioral Economic Models, Conceptual Frameworks and Related Methods

Behavioral economic models integrate microeconomic theories with behavioral analyses such as reinforcement and operant conditioning which refer only to overt relations between behavior and the environment. The former conceptualize choice behavior as a competition between inferred motivational states *within* an individual [Picoeconomics; 9, 10, 11] whereby some utility function is maximized [i.e., rational theories 12, 13]. Additionally behavioral economics does not assume humans exhibit consistent preferences over time [10]. As such, behavioral economics employs a molar paradigm for understanding choice behavior that connects controlling variables or constraining conditions (e.g., price, availability) to aggregations of behavioral units (e.g., substance use over time), integrating environmental constraints and variability over time [14, 15]. In contrast, molecular approaches connect specific controlling, explanatory variables (causes) to each behavioral event (e.g., each instance of alcohol consumption) [16] and they assume that events that cause behavior must be temporally contiguous with the behavior [cf. 17]. Examples of molecular approaches include strict behavioral perspectives such as non-mediational input-output analyses that avoid inferences about the internal operations of the “black box” as well as approaches implicating more inferential psychological processes or variables between stimuli and single behavioral events (e.g., social learning, expectations for the effects of substances, conditioned and unconditioned responses, appetitive or aversive motivational states). Importantly, in accounting for large-scale behavior patterns, molar theories presume that controlling variables representing the temporally extended environment are present and actively influencing each behavioral unit [16].

Reinforcement and Operant Conditioning—The relationship between rate of responding and reinforcing effects is complex, but here we offer a general introduction of behavioral analyses to illustrate how these molecular approaches have informed molar-level behavioral economic concepts. According to reinforcement `theory', events or stimuli that follow a response are reinforcers if they increase (or punishers if they decrease) the probability of repeating the response. The reinforcing value (or “essential value”) of a drug at a given dose is defined by the slope of its demand curve [i.e., by how much responding it elicits across a range of response requirements; 18]. For example, cocaine at 1 mg/kg has one slope as the response requirement changes and cocaine at 2 mg/kg has a different slope as the response requirement changes. However, the relationship between drug responding and dose at any single response requirement is biphasic: at low doses, responding increases with dose, whereas at higher doses, responding declines with further increases in dose. One interpretation is that high doses are less reinforcing though several different explanatory mechanisms have been advanced to explain this relationship [e.g., 19]. For instance, higher doses may disrupt ability to respond (direct effects of the drug – sedation, hyperexcitation); additionally, satiation is more likely to occur at higher doses.

Learning theorists have more recently begun to adopt behavioral economic principles as a means for scaling the value of a reinforcer [18]. Indeed, the basic contingencies that characterize behavioral analyses tend to parallel the constraints (prices, budget) modeled in economic theories [12] and the foundation remains constant such that as unit price increases, consumption positively decelerates. The `unit price' can be conceptualized as a ratio of the response requirement to the dose of drug per ingestion. Although different response requirements and reinforcer magnitudes can comprise the same unit price, consumption remains relatively equal across the different combinations. As such, within a certain range of doses of drug, response requirement and reinforcer magnitude are said to be functionally equivalent because manipulating response requirement (e.g., doubling the effort) it is the same as manipulating reinforcer magnitude in the opposite direction (halving the reward) [3, 20].

Behavioral Theories of Choice—In addition to assessing direct constraints on access to substances, molar accounts of behavioral choice also consider availability of reinforcers other than substances and the constraints imposed on access to them [21]. Behavioral Theories of Choice (BTC) consider how an individual's behavior is allocated among a set of available activities. The relative effort put forth to gain access to a particular consequence (substance use) is broadly defined as the reinforcing value [21]. BTC offer a picoeconomic approach [c.f. 10] that largely overlaps with traditional behavioral economic theories, but emphasizes the relative value of a commodity (e.g., substance) when more than one reinforcer is concurrently available [22]. This ecological emphasis is well suited for addiction research because it parallels real life situations in which users choose from an array of alternate reinforcers [23]. BTC include principles of the Matching Law and Relative Reinforcing Efficacy (described below), as well as the economic axiom that consumption decreases as access or availability of a reinforcer decreases.

Matching Law: The matching law is a mathematical relationship that quantifies choice behaviors. Although it originates from operant conditioning, it may be considered a BTC insomuch as it attempts to explain choice behavior in the larger context, predicting direct proportion between all emitted behavior directed towards a particular activity (relative responding) and all obtained reinforcement (relative reinforcement rate) from that activity [24]. Although it did not originate from economic theory, the focus on responses in the context of concurrent reinforcements is analogous to the hyperbolic discounting models (described later) that do originate from economic theory [c.f. 25, 26, 27].

The matching law equates response ratios to reinforcer ratios and posits that strength and duration of reinforcement affects behavior, which in turn is reflected in the relative rate of response. The relationship is directly proportional such that higher rates of positive reinforcement result in higher relative response rates [24]. This is best described with concurrent reinforcement schedules. A subject is presented with three images—a slice of cherry pie, apple pie, and lemon pie—which the subject chooses by pointing to an image. These images are presented for a given length of time. After viewing the image (e.g., 30 seconds time block), if the rate of monetary reinforcement was 100% of 10 dollars awarded every thirty seconds a subject selected the apple pie image, 80% of 10 dollars (8$) for selecting lemon, and 50% of 10 dollars (5$) for selecting cherry, matching predicts that the response rate will be higher for selecting the apple pie image, and in direct proportion to the reinforcement rate. The time interval of image exposure can also be varied with similar predicted outcomes.

The matching law, in its simplest form, does not account for other factors (e.g., financial need, negative memory associations with apple pie) and it has been revised to take into account other factors such as reinforcer bias and under-matching [28, 29]. The equations for the original strict matching form (1) and the more generalized function (2) appear below. The latter function takes into account bias "b" of reinforcement and alterations to strict matching (a). When a =1 and b=1, as predicted by Herrnstein, it is considered strict matching. Undermatching (a <1) and overmatching (a > 1) is present when the response ratio is less or more extreme than predicted by matching, respectively.

$$\frac{P_1}{P_1+P_2+P_3+\ldots+P_n}=\frac{R_1}{R_1+R_2+R_3+\ldots+R_n} \quad (1)$$

Reproduced from [30].

$$\frac{R_1}{R_2}=b\left(\frac{r_1}{r_2}\right)^a \quad (2)\ \text{Reproduced from}$$

[28]. Herrnstein's matching principle [30] creates a framework to empirically study choice behavior, but is not without criticism. McDowell notes, for instance, a failure to incorporate important variables such as reinforcer magnitude [29].Additionally, matching is strongest when using concurrent, variable-interval schedules, but becomes less so under different schedules of reinforcement. A failure to conform to the principle can signify that some reinforcers are not accounted for in the model [31]. For instance, in a closed, one-sided discussion about juvenile delinquency, participants received statements of agreement (“I totally agree with you.”) from confederates at independent, variable-interval schedules; participants' response to the reinforcement was operationalized as amount of attending behavior demonstrated (eye contact, body orientation). Results showed that matching was only likely in the first five minutes of discussion and thus highlights some of the limitations in pure application of matching law [32]. Although the underlying framework of this principle informs much of behavioral economics, there has been a call for more precision in application of the principle [33]. Accordingly, extensions and modifications of the original law have been formulated, though the underlying principle remains valid [29].

The concept of reinforcement has also been extended to describe ecologically realistic situations whereby individuals are faced with behavioral choices in the context of other factors such as probability of reinforcement and reinforcement value relative to other commodities [e.g., food; 34] and opportunity cost [35]. Central to behavioral economics is the basic relationship between price and consumption of a commodity, a tenant from which the demand curve is based. In its simplest form, the relationship is inversely proportional. That is, as price decreases consumption increases (see Table 1). In much the same way as the matching law has been modified to improve utility, the simple proportion between consumption and price below can be modeled in various ways (e.g. linearly, exponentially) as the parameters require [36, 45]. The second equation is a variant of Hursh and colleagues' (1988) where *C* is the predicted consumption at a unit price of *P, L* is the price intercept, parameter *a* determines the slope and parameter *b* determines acceleration of the resulting function.

$$C \propto -P$$

$$\text{Ln}\ C=\ln L+b\,(\ln P)-aP\ \ [36]$$

Relative Reinforcing Efficacy (RRE), RRE represents an ecologically-minded conceptualization of decision making that attempts to account for diverse phenomena related to the strengthening effects of reinforcement [37]. Within the purview of addiction, RRE refers to the ability of a drug or drug dosage to maintain or strengthen a behavior relative to other consequences [37]. This theoretical construct is not intrinsic to a drug or dose, but instead results from interactions between the drug and numerous biological and environmental factors [38]. RRE can be assessed by quantifying the amount of behavior an individual is willing to expend to obtain a certain drug or dose, relative to other reinforcers or other drug doses [4]. Measures of reward value or demand use an independent, quantifiable metric such as time, money, or enjoyment to scale the value of a given commodity/reinforcer (substances, social activity) and these factors are highly relevant to the substance-user's real life decision-making. More specifically, RRE measures assume that humans' valuation of rewards is related to the frequency of engagement in a particular activity (the element most consistent with orthodox definitions of reinforcement) as well as their subjective appraisal of the activity (some events may be performed out of obligation or a temporary contingency). Indeed, the relative subjective pleasure associated with drug versus drug-free rewards is an important element in some reinforcement based theories of addiction that are rooted in contemporary neuroscience approaches which view the diminished pleasure associated with drug free rewards as contributing to increasing substance abuse and vulnerability to relapse [39, 40].

Measures and Tasks—The below assessment tools have been described as cost and time efficient, can be administered in clinical settings [4] and have been used to assess the relative value of multiple reinforcers, including nicotine [e.g., 41, 42], caffeine [e.g., 43], alcohol [e.g., 36], and food [e.g., 44].

The *Monetary Choice Task* [MCT; 45] provides researchers with a tool for assessing the extent to which social information (i.e., opportunity to view others), an evolutionarily-oriented reward, can be substituted for money. Hayden and colleagues [46] quantified the reward value of social information in humans by determining the extent to which viewing images of members of the opposite sex on a computer screen could be substituted for money. More specifically, participants are given the option of viewing a grey square accompanied by a 500ms sound wave of money pouring from a slot machine or a photograph of an individual of varying attractiveness accompanied by the same sound but for variable time duration. Admittedly, although social information (e.g., what others look like) is hugely important in social decision making, it is a far different type of “reward” from substance use. However, the MCT is sensitive to changes in an individual's valuation of non-monetary rewards (social information) relative to monetary rewards, and with additional research it may provide yet another behavioral task for measuring the reinforcement value of substances relative to other rewards.

The *Multiple Choice Procedure* [MCP], originally developed as a laboratory measure [47, 48] and later as a questionnaire [49], is intended to provide a relative reinforcing value for substances by determining the relationship between substance preferences and alternative reinforcers. This assessment tool considers both the magnitude of substance reinforcer (i.e., the dose) as well as the length of delay associated with the alternative reinforcer (e.g., money). More specifically, the MCP presents the participant with a series of discrete choices between a dose of a substance or an increasing amount of money (e.g., for each choice below, select whether you would prefer to receive the cigarettes – 1 pack - or the monetary value – 59 cents). Experimenters can choose to include a delay element by comparing participants' choices when money will be delivered immediately (today) and when money will be delivered after a delay (a week later). The crossover point (main outcome variable expressed in dollar value) is reached once the participant chooses the money over the substance [47] and higher values indicate higher relative reinforcement value for the substance. Following completion of the form, one of the participant's choices is then randomly selected and the substance or money is awarded. MCP data with several substances have also been successfully analyzed as behavioral economic demand curves [see 50].

The MCP has been used with a variety of substances including cocaine [51], sedatives [48], caffeine [52] cigarettes [47], MDMA [53], opiates [54], marijuana [55, 56], methylphenidate [57] and IV nicotine [58]. Moreover, responses appear sensitive to reinforcer magnitude [47, 51, 57], drug dependence [52] and deprivation [47]. Correia & Little [59] attempted to modify both the laboratory and survey forms of the MCP to study the relative reinforcing value of alcohol. Although both forms were related to alcohol use variables and were sensitive to manipulations in reinforcer delays, college students had higher cross-over points on the survey version compared to the laboratory version (i.e., sensitivity to the amount of alcohol available differed) and correlations between the two forms were not significant. To address concern regarding the reliability of the effects of reinforcer magnitude (alcohol dose) on the relative reinforcing effects of alcohol, Benson, Little, Henslee and Correia [60] increased the range of alcohol doses available on the MCP (3 instead of 2) and subsequently demonstrated increased reliability between the laboratory and survey versions of the MCP.

The *revised Pleasant Events Schedule* [PES; 61, 62] assesses the frequency of participation in (e.g., never = 0, occasionally = 1, often = 2) and amount of “enjoyment/pleasure “(e.g., mild = 0, moderate = 1, extreme = 2) derived from 330 different activities (e.g., going naked, social drinking, being with friends) in the past 30 days. The items are completed twice so that separate ratings are collected for activities that took place during use of substances and for activities that did not (i.e., 4 data points for each activity). To calculate the level of reinforcement derived, the frequency and enjoyment ratings are multiplied so that two scores are generated for each activity (i.e., ExF while using, ExF not using). A Relative Reinforcing Efficacy (RRE) index can then be calculated by dividing the total substance-related reinforcement score by the sum of the total substance-related and substance-free reinforcement scores. Amount of reinforcement derived from non-substance related activities on the rPES has been found to inversely correlate with alcohol and substance use quantity, frequency and related problems [61]. Additionally, binge drinkers systematically reported lower levels of reinforcement from substance-free activities on the rPES compared to non-binge drinkers [63]. Interestingly, heavy college student drinking is associated more closely with non-substance related peer and sexual activity (social rewards) and not with global deficits in substance-free reinforcement [64].

The Relative Behavioral Allocation and Enjoyment - Adolescent Reinforcement Survey Schedule-Substance Use Version [ARSS-SUV; 23] is a significantly shortened version of the rPES modified to include activities that are more relevant to adolescents and young adults. Specifically, it measures an individual's frequency of participation in 45 different activities over the past month as well as the amount of enjoyment derived from those activities. Increases in proportional reinforcement derived from non-substance related activities have been documented among college students who decreased their drinking 6 months following a single session intervention [23]. Additionally, the ARSS-SUV index has been correlated with number of drinks per week and demand intensity (consumption when drinks are free), derived from an Alcohol Purchase Task (described below), among a sample of undergraduates [4].

An individual's allocation of discretionary (non-obligatory) monetary expenditures for substance use, versus savings, can be used to measure the reinforcement value of a substance relative to other available reinforcers for purchase as well as assess temporal discounting of future rewards [i.e., savings are required to gain access to future rewards; 65]. Substance specific expenditure indexes, such as the Alcohol and Savings Discretionary Expenditure [ASDE] index [65], are computed by gathering information about income from financial documents (e.g., pay-stubs, tax returns, sales receipts) and using U.S. federal consumer expenditure surveys [66] as well as Time Line Follow Back Interviews [67] to help participants recall monetary income and expenditure patterns over the past year. Expenditures are then categorized into obligatory (e.g., rent, utilities) or discretionary subcategories (e.g., consumable goods, alcohol, tobacco). The ASDE index is calculated by subtracting the proportion of discretionary expenditures spent on alcohol from the proportion of discretionary expenditures put into savings over the past year. Scores can then be compared against a subject's resolution to abstain from the substance or to moderate use. A lower ASDE score is theorized to reflect a greater balance between short-term (substance now) and long-term (savings for later) monetary allocations which in turn suggests more moderate use of a substance [68]. Thus the ASDE functions to bridge reinforcement value (immediate reward – money actually spent on alcohol) with temporal discounting (savings as a delayed reward: retirement, college funds, vacations, home improvements).

Hypothetical purchase tasks have been created for alcohol [Alcohol Purchase Task; 36] and cigarettes [Cigarette Purchase Task; 69]. In these tasks, a scenario is described in which a participant has the opportunity to purchase a substance at varying cost amounts. The question asked in each scenario is essentially, "how many X (drinks) would you consume if they were Y amount (1$) each?" The scenario can be modified to assess demand at the state (consume right now) or trait (consume in general) level. Hypothetical purchasing was first assessed by utilizing `play' money for purchase during interviews [70], but proved to be time-consuming and ill adapted for larger testing [69]. Currently, short questionnaires (administered via computer or pencil and paper) are employed to model demand for substances as a function of unit price. *Demand curves* are then generated with specialized software to provide graphic displays of consumption of substances as a function of cost. Five distinct indices of demand can then be determined from such a curve [37]: P_{max} (point at which consumption moves from being inelastic to elastic), O_{max} (maximum expenditure), breakpoint (first price to completely suppress consumption), intensity (consumption when unit is free), and elasticity (sensitivity of consumption to increasing price). Sensitivity of these tasks to substance use status, craving, withdrawal and intervention is discussed below. Intensity of alcohol demand, but not the other four indices, has been found to correlate positively with delay discounting [71].

Delay discounting (DD) refers to the devaluation of a reward as a function of time between the response and the delivery of the reward (i.e. 10$ now is `worth more' than 20$ a month from now) [26, 72, 73]. The methodology has been successfully applied across populations and substances, and measures used to assess the extent of discounting tend to correlate with level of habitual drug use as well as self-report measures of impulsivity and even offer insight into elements of behavioral control that are typically compromised in addiction [73]. This latter feature makes DD paradigms especially applicable to substance use and drug dependence, as impulsive choices and "loss of control" are hallmarks of addictive behavior [74]. It is important to note that unlike measures that assess demand and reward value of a commodity, DD measures the role of delay in the relative valuation of a reward and in particular how the value of a given reward changes as a function of delay.

Two models of delay discounting have been proposed—exponential and hyperbolic. The exponential model assumes a constant rate of devaluing—the value of the reinforcer decreases by the same proportion across time [e.g., 75]. However, current research indicates that a hyperbolic function is more empirically supported and provides a better fit to actual substance use patterns [76–80]. The hyperbolic function assumes that the proportion of devaluation decreases across time. And with this decrease in devaluation, preference reversals [see 73; e.g., less money now vs. more money later; more money for less alcohol now vs. less money for more alcohol later]— that ostensibly reflect reduced capacity for decision making and behavioral control—can be identified. By way of example: Offer (a) is 10$ right now or 20$ in six hours. Offer (b) is 10$ in 100 hours or 20$ in 106 hours. An exponential model predicts no difference in discounting between offer a and offer b. However, a hyperbolic model predicts that for time intervals far enough in the future (e.g., 100 hours), the delay to reward affects discounting less than a sooner time interval (i.e., offer a, waiting 6 hours now). The difference is in when this interval is placed in time. More specifically, even though the differences in amount of money and the time interval are equal in offers a and b, the hyperbolic model assumes that waiting 6 hours now (offer a) factors more heavily on decision-making than waiting 6 hours a hundred hours from now (offer b), The equation used, as developed by Mazur [81], is of the form:

$$v_t = \frac{V}{1+kt}$$

Where $\mathbf{v}_t$ is the discounted value of the reinforcer at the delayed time, **t**; **V** is the objective value of the delayed reinforcer; and **k** is the derived constant that determines the rate (or degree) of discounting. Procedures used to derive the discount rate (k) will present subjects with a choice of an immediate reward (either hypothetical or actual) or a delayed, larger reward. Then the amount of immediate reward is adjusted until the two amounts are chosen equally often. Alternatively, some measures incorporate probabilistic elements and adjust the delay to reward (e.g. Experiential discounting Task). In one such permutation, a large hypothetical monetary reward was offered with varying probability versus an immediate, smaller reward [82]. There are also tasks that offer dual types of reinforcers, splitting choices between monetary rewards and various substances, such as alcohol [Alcohol vs. Money Task; 83], cocaine [Cocaine vs. Money Task; 84], and nicotine [Smoking Behavioral Choice Task; 79, 85, 86]. A task may forego monetary rewards altogether and only offer drugs as either immediate or delayed rewards [79, 85, 87]. Whichever the approach, each equivalence obtained—termed the *indifference point*—can be aggregated and plotted as an *indifference curve*, and then used to derive the rate of discounting. This point of indifference refers to the value at which the subject chooses either option equally, and no value difference is associated with the choice.

The Kirby [88] is a short 27-item questionnaire of delay discounting that asks participants to choose between larger amounts of money that could be received at a later time and smaller amounts that could be available immediately. Three different indifference point values are identified for small, medium and large delayed-reward amounts though no discount function can be calculated because of limited indifference points. The Kirby has been used in the context of both hypothetical [89] and real-reward [90] assessments and responses on the measure strongly correlate with discount functions derived from questionnaire based hypothetical measures of delay discounting.

The *Experiential Discounting Task* [EDT; 91] exposes participants to choice consequences in real time (i.e., during the assessment period) to model naturalistic choice contexts associated with delayed and immediate outcomes. Multiple blocks of choices are administered for each delay assessed (0, 15, 30 or 60 seconds) in which the participant chooses between 1) a standard amount of money that would be delayed with a set probability of actually being received (e.g., 40%), and 2) a changing amount of money with no delay that is completely certain. Participants make enough choices in each block until a point of indifference is reached (i.e., equal number of choices recorded for each option). The EDT is sensitive to sleep-deprivation [91], acute effects of alcohol consumption [92] and cigarette smoking status [Smokers vs Non-smokers; 93]. The task also features a probabilistic component for the delayed choice, which may also more realistically represent choice conditions outside the laboratory. Another benefit of this task is that it might be more suitable to assess state changes in impulsive choice, including changes related to acute drug administration or withdrawal [74]. Of note though, there is mixed evidence about the concordance between discounting measured on the “experiential” task and more conventional discounting tasks [92–94].

One consideration in DD tasks has been whether behavior is different when rewards used in the task are real versus hypothetical. For practical reasons, it is often not possible to offer real rewards (e.g., illegal substances, large sums of money) in the laboratory, and therefore researchers often use hypothetical rewards. Several studies have directly compared DD behavior with real and hypothetical rewards, in the same subjects, andhave found little difference between the two [95–99]. Thus, a single equation can accurately measure indifference curves with both hypothetical and actual outcomes and the two methods yield comparable results [69, 73]. In practice, using hypothetical rewards is more cost efficient and allows for assessment of delayed outcomes that take place far into the future, which may better reflect decisions regarding drug use.

Table 2 lists and describes the various behavioral economic tasks and methods discussed above based on the theoretical frameworks from which they were derived.

III. Context: Who, What, When

The context in which choices are evaluated and selected represents a strong and important influence on the decision making process. The current section addresses contextual factors that may influence assessment and subsequent interpretation of data from behavioral economic paradigms of substance use.

Reliability within individuals—In contrast to many personality based risk factors for addiction that are often conceptualized as immutable traits, behavioral economic measures largely presume that the relative value of a substance varies as a function of both visceral states (e.g., craving) and the availability of alternative reinforcers. As such, there are limited data regarding the reliability of these measures within individuals over extended periods of time. The reliability of monetary delay discounting was deemed adequate within smokers [95] and non-drug dependent individuals [100] over a one-week period, whereas other studies report only moderate reliability over periods of 6 weeks to 3 months [101, 102]. On the Alcohol Purchase Task, 4 out of 5 indices of demand had acceptable reliability in college students over a two-week test period [4]. Further research is needed to determine the amount of with-in subject heterogeneity that characterizes behavioral economic measures throughout the substance use trajectory. Additionally, it is important to identify factors that co-vary with changes in reward value for substances over time (e.g., smoking behavior).

Acute effects of substances on behavioral economic tasks—Several studies have examined the acute effects of substances on behavioral economic measures using placebo controlled acute drug administration designs. Alcohol consumption has been shown to either decrease discounting [103] or to have no effect [92, 104]. No alterations in discounting were observed following variable amounts of marijuana consumption [56]. Additionally, relative to the placebo and low dose (10mg) conditions, D-amphetamine (20mg) was found to reduce delay discounting [105]. Of note, administration of alcohol (0.8 g/kg) increased discounting in a study using the experiential discounting task, a real-time measure of delay discounting [92]. It is possible that the real-time assessment of discounting may better capture state measures of discounting, such as those related to acute drug administration.

Relatively few studies have examined the acute effects of other illicit drugs on behavioral economic indices. In participants with a history of poly-substance use, the anti-convulsant levetiracetam (4000mg) increased the cross over point on the MCP whereas diazepam (30mg) did not [106]. In another study, cannabis users received placebo, marijuana, triazolam, methylphenidate, or hydromorphone over five sessions in a procedure providing choices between the drug and money. Marijuana significantly increased the dollar value at which subjects choose drug over money on the Multiple Choice Procedure, but demand did not change with the other drugs [107]. In that study, participants did not receive the outcome of their choice (money or drug) until the last day of the study, and they received only one of their many choices. The authors speculated that the long delay between a choice and receiving the reinforcer contributed to the modest effects observed. Finally, in a study of non-dependent cocaine users, researchers found that alcohol consumption significantly increased participants' choice of cocaine over an alternative substance-free reinforcer (money) and thus increased the reinforcing value of cocaine [108].

Initial Abstinence, Deprivation and Craving—In an attempt to explain decisions made against one's self-interest, with subsequent experiences of being `out of control,' the Visceral Theory of Addiction (VTA) posits that `visceral factors' induce drive states (hunger, thirst, sexual desire, physical pain, moods, craving for a substance) that can interfere with volitional decision-making [109]. Although visceral factors are largely autonomic triggers, the choice to act is still founded in volition; hence, visceral factors render choices both volitional and autonomic (e.g., eating pie is a willful choice but hunger is not). Briefly, the model is based on two ideas: 1. acute visceral factors (e.g., craving to smoke) are conceived as powerful motivation states that disproportionately influence behavior (e.g., stopping to buy cigarettes), and often to the detriment of other goals (e.g., not arriving to work on time), and 2. individuals tend to discount the influence of visceral factors on behavior [109]. An extension of the VTA focuses solely on craving as the primary visceral factor leading to addiction [110, 111]. Although there are many theories regarding what craving is, the construct is of particular relevance to the current paper as discounting or neglect of future craving can impact initial use of a substance [112] and visceral factors (e.g., craving) can increase the demand for and inflate the relative value of a substance [e.g., 71, 113].

Several behavioral economic measures have demonstrated sensitivity to acute craving and deprivation states and to cue-elicited craving paradigms. For instance, self-reported craving, a confirmed index of deprivation, has been associated with delayed reward discounting and intensity of demand on the Alcohol Purchase Task [71, 113] and with greater relative value of alcohol on a money versus alcohol task [111]. Similarly, craving, urge and desire to use have been related to behavioral economics assessments of the relative value for opiates [112] and cigarettes [86, 114]. Several other studies have shown that short-term abstinence increases demand for substances. Within-subject designs have illustrated that nicotine deprivation, relative to ad-libitum smoking, is associated with increases in delay discounting of both money and cigarettes [115] and increased preference for immediate cigarettes over delayed money [116]. Additionally, deprivation from opiates, in opiate-dependent participants, increased discounting on a hypothetical purchase task for both money and heroin relative to the satiated state [117].

IV. Populations and Drug Types

Patterns of behavior also differ in drug users (e.g., never user, current user, ex-user; dependence, abuse, sober) compared to nonusers, and across drug types [e.g., nicotine, alcohol, illicit drugs; 74]. These differences may reflect either changes in reinforcing value of the substance or changes in reinforcing value of the drug relative to other reinforcers associated with repeated use and pathological consumption patterns or they may reflect pre-existing group differences.

BE measures between chronic users and never users and between drug types —Numerous studies have sought to determine whether behavioral economic tasks can discriminate between use status across several types of drug. In general, current substance users exhibit more discounting on behavioral economics tasks than never users or ex-users. For instance, heroin-users discount at significantly higher rates than never-users [79, 85, 87, 88, 118], and smokers discount more than nonsmokers (although ex-smokers resemble nonsmokers more than smokers) [87, 95, 119–122], active amphetamine and heroin injectors more than never users [118], and crack cocaine users more than never users [123]. The only exception to this pattern has been with marijuana use [124, 125]. Interestingly though, Kollins [125] found that younger age of first marijuana use was associated with steeperdiscounting.

Behavioral economic measures by current users and ex users—Research attempting to distinguish between current and former users has yielded mixed results. Although current and ex users of cocaine [90, 126], alcohol [90] and marijuana [124] do not appear to have different discount rates, differences have been reported between current and past users of heroin and opium [79, 90] and heroin and amphetamines [118]such that current users evidence higher discount rates than ex users. In one study, current smokers discounted at the same rate as past smokers [87] whereas in another, current smokers discounted more [127]. It remains to be determined whether quitting use of a drug decreases the level of discounting.

BE measures between different types of drug use—Several studies have compared discount rates across samples of users of different substances of abuse. Bornavalova [89] found that crack-cocaine abusers discounted significantly more than heroin abusers after both groups abstained from their drugs for one week. Kirby and Petry [90] found that current and past cocaine abusers and heroin abusers discounted more than both nondrug users and current or past alcoholics (alcoholics did not differ from the controls). Finally, Businelle and colleagues [119] found that there were no differences in discounting among drug users who were dependent on one substance versus more than one substance at the same time. Although these findings suggest that discount rates may vary across users of different classes of drugs, numerous other variables could affect the behavior independently of the drug type, including but not limited to duration and chronicity of drug use, lifestyle factors, socioeconomic status and use of multiple drugs.

BE measures by different patterns of drug use—Discounting measures have been not only been used to compare substances users to controls, but also drug users with different levels of use. Heavy smokers show steeper discounting for money than chippers (those who smoke with regularity but do not develop nicotine dependence) [86], and discounting rates are positively correlated with daily nicotine intake [80, 128, 129]. Heavier smoking and higher nicotine dependence among adolescent smokers was associated with higher scores on measures of demand on the Cigarette Purchase Task [130]. At the same time, MacKillop and colleagues [71] reported that discounting did not vary in relation to number of alcoholic drinks per day in heavy drinkers who consumed between 18 and 60 drinks per week.

V. Validity of the Behavioral Economics Approach

To what extent does behavioral economics provide a valid model to explain addictive behavior? As discussed at the outset of this paper, the “problem” that a behavioral economics perspective purports to describe is the inherent irrationality of the addict, of engaging in behavior that results in detrimental consequences. As eloquently articulated by Rachlin [12], [see also 131], a behavioral economics model may shed light on this perplexing problem. Indeed, the separate constructs and measures used in behavioral economics (e.g., discounting, demand, relative reinforcing efficacy, savings and discretionary expenditures) each appear to have some predictive (e.g., treatment outcome, attrition, relapse, response to intervention), and external validity (e.g., convergent – correlated with measures of impulsivity and risk taking; divergent – lower in populations without substance dependence compared to those with substance dependence). Specific evidence for validity includes the observation that substance-dependent individuals discount more steeply than never users [132, 133]. As described above this applies to smokers [87], heavy drinkers [134] and opioid dependent individuals [88, 118]. Moreover, a recent meta-analysis of studies comparing delayed reward discounting between control groups and groups exhibiting addictive behavior confirmed that it is higher in the latter group and even higher among individuals who meet criteria for an addictive disorder [133]. With regards to construct validity (e.g., Alcohol Purchase Task - five distinct indices capture the theorized structure of the demand construct), it remains to be determined whether the measures presented in this review reflect perturbations in the same construct or whether they reflect different dimensions underlying related processes. Epstein and colleagues [135] posit that delay discounting and reinforcing value are closely related in that the two approaches share a common metric of unit price and both assess the same process but do so with different temporal characteristics. This interpretation would then suggest that discounting and demand tap the same construct but do so through a different means of assessment.

Several questions remain concerning the validity of these measures across substance s of abuse, phases of use and in the context of acute use as well as deprivation. Behavioral economic measures may be useful predictors of behavior controlled by only some drug classes and not others such as those with lower abuse potential [e.g., 133]. Additionally, the basic principles may apply differently depending on where the users are on the developmental trajectory (from occasional user to dependence). Finally, there is growing yet limited evidence that acute administration of drugs increases discounting [e.g., 92], and that cue-elicited craving [e.g., 113] and drug deprivation effects [e.g., 115, 116, 117] increase discounting as well as demand.

VI. Clinical Implications

Behavioral economic theories and the tools derived from them offer potential to inform and guide substance use intervention and treatment. They may help to identify individuals who are more vulnerable to problematic substance use or more resistant to treatment. For example, one study of heavy-drinking college students found that indices derived from an alcohol demand curve (i.e., maximum alcohol expenditure, sensitivity of consumption to increasing price) predicted alcohol treatment response 6 months later [136]. That is, students who demonstrated greater demand for alcohol at baseline (i.e., willing to pay more for a drink, less sensitive to increasing cost) were less likely to change their drinking behavior following the intervention. Furthermore, adolescents who discounted monetary rewards more on the Experiential Discounting Task were less successful in abstaining in a smoking cessation program [137]. Among a sample of adolescents enrolled in a clinical trial for marijuana abuse and dependence, delay discounting predicted several different treatment outcomes [138]. Also of note, even after controlling for nicotine dependence and sensation-seeking, delayed reward discounting (Monetary Choice Questionnaire) predicted days to first smoking lapse in a sample of heavy drinkers undergoing smoking cessation treatment [139]. Finally, greater discounting at baseline predicted smoking status (currently smoking) 24 weeks later in a treatment sample of post-partum women [140]. Together, these findings suggest that behavioral economic measures can potentially serve as a more implicit marker for treatment readiness and may help predict outcomes (percent days abstinent, time to relapse, treatment retention). Additionally, elevated scores could help clinicians identify higher-risk patients for specialized skill-building to increase inhibition, improve planning and decision making, heighten financial precautions and increase involvement in alternative non-substance related activities.

Behavioral economic methods may also be valuable in the assessment of treatment medications. As noted by Bickel and colleagues [141], changes in price sensitivity or elasticity of demand for a substance measured in the laboratory may provide proxies for the efficacy of drug abuse medications (e.g., methadone). Effective medications would be expected to shift (reduce) the demand for the abused drug as price increases. Demand curves can also be used to evaluate the relative motivation for substances versus other rewarding alternatives [141, 142]. For instance, adolescent smokers with lower motivation to change smoking behavior exhibited greater demand intensity (number of cigarettes consumed when free) on the Cigarette Purchase Task [130]. Behavioral economic measures of demand and elasticity may therefore provide an objective and sensitive index of motivation to reduce or abstain from substance use. Accordingly, systematic data on the relationship between behavioral economic indices and self-report measures of motivation to change behavior (e.g., quit or reduce substance use) would be valuable in the context of treatment.

Behavioral Theories of Choice and related tools may also inform prevention policy and interventions [143]. For instance, encouraging increased participation in alternative enjoyable, alcohol-free activities may help reduce actual alcohol consumption [36]. This idea was supported by a study in a nonclinical sample, in which increasing the number of available substance-free activities led to decreases in drinking [144]. In another study comparing the effects of contingency payments for 1 day versus 14 days of abstinence, adult smokers assigned to the latter condition demonstrated a larger increase in the amount of delayed hypothetical money they would accept over different cigarettes choices and were less likely to choose the smoking over the money option [145]. Additionally, the Alcohol Savings and Discretionary Expenditure index has proven to be sensitive in predicting resolutions across groups with variable drinking intensity (i.e., light, moderate, or heavy drinking), at follow-up times of one and two years, as well as among groups of problem drinkers who have and have not undergone interventions [65, 68, 146].

More recently, researchers have begun applying computer-based cognitive remediation strategies to target the executive dysfunction (poor planning, sequencing, inhibition) typically observed in chronic substance-dependent populations [see 147, 148]. For instance, in a sample of stimulant dependent individuals, those who received working memory training showed significantly reduced delay discounting compared to participants in the control condition [149]. Interestingly, one study has tested a substance abuse treatment intervention behaviorally targeting delay discounting [Advisor-Teller Money Manager; 150]. Participants who received individualized feedback about spending or substance use had significantly lower rates of delay discounting and less cocaine use over time, compared to controls. Furthermore, for the sample as a whole, steeper increases in delay discounting were associated with increased cocaine use (i.e., decreased abstinence) over time suggesting that changes in discounting predicted a return to drug use. This study provides promising evidence for the feasibility of designing treatment programs around the principles derived from behavioral economics and suggests that changes in discounting may be associated with changes in substance use.

Behavioral economic measures can also help elucidate decision making processes underlying behavioral addictions and other health-risk behaviors (e.g., binge eating, compulsive shopping; failure to protect against pregnancy or sexually transmitted diseases, riding with an intoxicated driver, sharing a needle) by quantifying the reinforcing value or discount rate for specific behaviors. Burgeoning research in the area of obesity suggests that application of behavioral economics tools may be useful in this regard [see 135]. For instance, obese women have demonstrated greater delay discounting than controls [151] and percent body fat has been associated with discounting for food, but not money [152]. Additionally, obese teenage smokers discount significantly more than non-obese teenage smokers which suggests that temporal discounting may be a trans-disease phenomenon [153].

Finally, some behavioral economic paradigms are starting to use non-monetary rewards that are specific to the addictive behavior under study (e.g., eating a food – binge eating disorder). Methods that assess response patterns to rewards specific to the behavior of interest have recently been developed to characterize decisions for hypothetical sexual activity [e.g., choice of different amount of sexual activity available after different delays or with different probabilities; 154]. One advantage of employing addiction-specific choice patterns over monetary outcomes is that impulsive decision making can be examined as it directly relates to the behavioral outcome of interest. Accordingly it is important to determine how behavior and addiction-specific response patterns are influenced by context (e.g., arousal, hunger, social environment) or whether they can be used to study ecologically valid behavioral outcomes (e.g., engagement in risky sex, binge eating). For intervention purposes, such measures could help identify at-risk individuals before they consistently engage in these risky behaviors or develop full-blown behavioral addictions (e.g., gambling, shopping).

VII. Recommendations for Future Research

Temporal sequencing—Most of the research on behavioral economics in drug abuse addresses relatively stable individual differences. However, there is evidence to suggest that these processes are dynamic and change throughout the drug use trajectory. As described above, with some forms of drug use, former users resemble nonusers on measures of discounting, indicating that the behavior may be influenced by the drug and return to baseline when the drug is removed. With other drugs, however, ex-users more closely resemble users, suggesting that in these cases, the discounting may reflect a pre-existing trait that contributed to the initial use of the drug. Further studies examining the time course of changes in discounting and demand among drug users will shed light on the question of whether drug use is a determinant, or a consequence of these traits [155].

Research with adolescents is ideal for exploring the role of discounting behavior across the developmental trajectory of substance use behavior. In a cross-sectional study comparing adolescent smokers (daily use), experimenters (no more than 3 cigarettes total for the first time in the past three months) and non-smokers, findings revealed that experimenters' rate of discounting did not significantly differ from that of current smokers but was higher than discounting rates observed for non-smokers [156]. Two longitudinal studies have examined the relationship between behavioral economic measures and substance use. Audrain-McGovern and colleagues [157] examined the likelihood of smoking progression from 9th to 11th grade in relation to involvement in substitute reinforcements including school-related clubs, perceived academic performance, and physical activity. In line with theories of relative reinforcing efficacy, they found a two-fold reduction in smoking among participants involved in other activities. Conversely, higher involvement in complementary reinforcers such as alcohol and drug use and peer smoking was related to increased likelihood of smoking progression over time. Whereas adolescents who were regular smokers exhibited steeper delay discounting at baseline, discounting did not directly predict smoking progression. Instead, delay discounting indirectly influenced smoking progression through its effects on complementary reinforcers such that adolescents with higher discounting rates had more involvement in complimentary reinforcers. Another study by the same research team measured cigarette smoking and delay discounting several times throughout the transition from adolescence to young adulthood [158]. Results indicated that delay discounting was stable over the time span and did not discriminate between the three different smoking trajectory groups identified with latent growth mixture modeling. These data suggest that delay discounting rate is more trait-like than state-like during the transition to young adult-hood and that despite being a strong predictor of smoking status and smoking patterns, does not appear to be altered by smoking (i.e., delay discounting is a facilitator of substance use). It remains to be determined how chronic drug use alters delay discounting rates and other behavioral economic measures. To what extent does the preexisting trait predict risk for use, escalation, or relapse, and to what extent does discounting change over the course of drug use?

Individual Differences—There is also much to be learned about individual differences in discounting and other behavioral economic measures. Sources of individual variability include personality variables, such as impulsivity [155, 159], neuroticism [160], extraversion [161] and sensation seeking [162]. Other contributing variables include psychiatric symptoms or psychopathology [163] and motives and outcome expectancies for substance use (e.g., enhancement, coping). There is also potential for research to identify genetic variants that influence discounting and other reward-related behaviors [e.g., 111]. Individual differences in delay discounting for instance may also map on to treatment preferences and inform treatment matching initiatives. In the context of a 12-week treatment of opioid dependence combined with contingency management, individuals with higher rates of DD at intake redeemed their voucher earnings significantly more often than participants who had lower rates of DD [164]. Additionally, in a treatment sample of cocaine-dependent outpatients, baseline DD predicted fewer days abstinent in a low-magnitude contingency management voucher condition (maximal value = $499/12 weeks) but this relation was not observed in a high-magnitude voucher condition (maximal value = $1995/12 weeks) [165].

Relation to emotion—Lastly, another fruitful avenue for research is the relation between reinforcing efficacy of drugs and mood state. In general, decision making abilities are influenced by emotional activation presumably because higher order cognitive functions (e.g., information processing, problem solving, task sequencing, mental flexibility) are less accessible. Negative emotions such as anxiety, tension and stressful life events likely increase the marginal utility of addictive goods and anticipation of future stress may result in increased immediate consumption [166]. Hirsch and colleagues [167] reported that participants high in extraversion discounted more steeply, but this effect was moderated by positive affect, such that individuals were even more likely to prefer an immediate reward when first put in a positive mood. Findings from a recent study also suggest that neuroticism interacts with unpleasant state affect in guiding decision making in a temporal discounting task such that among individuals higher in neuroticism, a larger reaction to a negative affect prime resulted in higher discounting rates than did a lesser reaction [160]. Additionally, induction of negative mood states was found to increase alcohol choice in the Multiple Choice Procedure among individuals reporting high levels of drinking-to-cope motives [168]. Affectively “hot” and “cold” decision making [see 169] appears to be captured by these measures and thus highlights the dynamic influence of cognitive and emotional interactions. These relationships between mood states, decision-making and the reinforcing effects of drugs and alcohol will likely further benefit from studies conducted in natural, non-laboratory environments that employ ecological assessments [see 170].

VIII. Conclusion

Throughout our review of the literature, it becomes apparent that the perspective offered by a behavioral economics view of drug abuse and addiction goes a long way toward answering questions reflecting the inherent irrationality of such behavior. Indeed, when viewed through a rational lens, the behavior manifested by those who abuse drugs just doesn't seem to make sense. Yet, the rapid growth of behavioral economics paradigms in recent years has demystified this behavior in many critically important ways. For instance, Rachlin's Relative Addiction Theory [12, 171, 172] suggests that the choices of addicted individuals may be considered rational depending on the time frame used to assess the utility maximization of a behavior [see also 166]. That is, choosing to consume drugs may offer the highest rate of return in the short run, especially in an environment deprived of sources of substance-free rewards, or among individuals with long histories of substance use who would experience little immediate utility from engaging in substance-free activities. Additionally, steep discounting may not always be an irrational choice, depending on the environment/learning history and the likelihood of obtaining the delayed reward. Hence, addiction might be viewed as a rational behavior in the short run, and prove irrational when viewed in the context of a longer time frame. Accordingly, addiction is irrational to the extent that substance users fail to make predictions and take actions that maximize reinforcement in the long run [12].

Moreover, and as discussed throughout this article, the data and resultant implications hold tremendous potential for shaping prevention, intervention, and even public policy efforts aimed at curtailing destructive substance use. As such, we strongly believe that the future is bright for implementation of behavioral economic approaches to the problem of addiction. It is our hope that this review will help provide researchers with an overview of the theories and tools needed to do so. No doubt though, many questions remain unanswered: To what extent can these methods be adapted for other health-risk behaviors or behavioral addictions? Can they serve as a reliable proxy for treatment motivation and outcomes? Can cognitive remediation strategies reduce discounting of future consequences and in turn reduce the addictive behavior? Furthermore, do behavioral economic indicators reflect stable personality traits and/or are they more state-like, shaped by drug use itself [see 173, 174, 175]? And to what extent do such relationships vary as a function of drug class or user status (e.g., experimenter vs. dependent user)? Future research will need to address these and other as yet unanswered questions. We believe that the potential that the behavioral economics stance brings to both theoretical and applied realms is great and should be built upon to stem the tide of these destructive behaviors.

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Table 1

Common Terms Used in Behavioral Economics

General Economic Terms	Definition
Unit Price	The expenditure given for an amount of substance and is expressed by the equation, P = R/A; where P is the price of reinforcer, R is the response requirement, and A is the reinforcer magnitude. Also, it is thought of as the ratio of response requirements to reinforcer magnitude [176].
Law of Demand	As price increases, consumption and demand decrease.
Demand Curve	Amount of consumed goods plotted as a function of price. (i.e. $C \propto -P$)
Elasticity (Unit Elastic/Inelastic)	"The proportional change in consumption as a function of proportional change in price" [37]. Elasticity is displayed as the slope of a demand curve. This quantity describes the sensitivity to changes in price. Demand is *elastic* when changes in price lead to greater-than proportional changes in consumption, and *inelastic* when they lead to less-than proportional changes [143].
Linear Elasticity Demand Curve	A demand curve equation that expresses consumption as a linear function of price. (i.e. $C \propto -P$)
Exponential Elasticity Demand Curve	A demand curve equation that expresses consumption as an exponential function of price. (i.e. $C \propto e^P$)
Discretionary Expenditures	Extraneous spending that does not pertain to necessary, recurring expenditures (e.g. mortgages, bills).
Reinforcer Magnitude	The quantity or duration of reinforcement.
Demand	A quantity of substance or reinforcer an individual is willing to obtain at the prevailing price.
Pmax	The point that identifies the change from inelastic to elastic consumption, and is characterized by the price of greatest magnitude of response.
Omax	The highest rate of response or output, which corresponds with P_{max}.
Reinforcer Interactions Substitution, Complimentary, Independent	These are terms that refer to a continuum of interactions between pricing of two reinforcers. If the price of reinforcer A increases as the price of reinforcer B remains fixed, a *substitution* results in increased consumption of reinforcer B. On the opposite end of the continuum is a *compliment*, which results in decreased consumption of reinforcer B. In the middle lies an *independent* interaction, where the consumption of B is unaffected by the price change of A.
Ratio Schedule	Response requirement to elicit reinforcement. The number of responses may be constant (fixed-ratio) or differ (variable-ratio) between reinforcers.
Temporal Discounting	The tendency of individuals to assign a lower value to rewards as they move further out on the temporal horizon
Expected Value/Utility	The weighted average of a price distribution, with the weights assigned likelihood by probability of consumption.
Discounted Value/Utility	The adjusted subjective value of a commodity once delays in delivery are accounted for.
Relative Reinforcing Value (RRV)	Also known as relative reinforcing efficacy, it refers to strengthening/maintaining properties of a drug or drug dose. It can be quantified as the amount of behavior used to obtain a substance relative to other rewards.
Matching Law	A quantitative relationship between a response ratio and a reinforcer ratio.
Intensity of Demand	The degree of consumption at a particular unit price. Typically, it is useful to measure the demand when the price is zero. (i.e. the y-intercept of a demand curve)
Substance-Free Reinforcement	Use of alternate reinforcers that strengthen responses without drugs.
Price	The quantity of money set for sale or purchase of a substance. In the context of behavioral economics, it can be any resource costs (monetary, time, health) that are associated with substance use [143].
Relative Reinforcing Efficacy (RRE)	See RRV above
Breakpoint/ Point of Indifference	The point (price) where consumption is zero. It is the x-intercept of a demand curve.

Table 2

List of Tasks and Measures

Tasks / Measures	Description
Hypothetical Purchase Tasks: Alcohol Purchase Task, Cigarette Purchase Task	Use purchasing scenarios to assess RRE by modeling substance demand as a function of unit price.
The Relative Behavioral Allocation and Enjoyment - Adolescent Reinforcement Survey Schedule-Substance Use Version	Frequency of participation and magnitude of enjoyment for 45 different activities is measured and a RRE index is calculated.
Revised Pleasurable Events Schedule	A generalized version of the above, assessing frequency of participation and magnitude of enjoyment for 330 different activities. A RRE index using a ratio of substance-related activities to total activities is calculated.
Multiple Choice Procedure	A series of discrete choices between a dose of substance or an increasing amount of money, to which the latter a delay in payment can also be introduced. RRE for the substance is obtained.
Monetary Choice Task	A choice between a neutral visual stimulus + fixed-duration sound of money, or a photograph of a person + variable-duration sound of money. The photographs varied in attractiveness. A reward value quantity is calculated and represents the extent to which viewing images can be substituted for money.
Demand Curves	A method of displaying demand for a substance as a function of unit price. Five distinct indices of demand are generated—P_{max}, O_{max}, breakpoint, intensity, and elasticity.
Hypothetical Questionnaire	Methods of obtaining demand data for items that are problematic to acquire (e.g. illegal drugs, large sums of money).
“Real-reward” Questionnaire	Methods that employ actual monetary or substance rewards (e.g. cigarettes) to obtain demand data.
Real-time reward – Experiential Discounting Task	Choice between a fixed amount of delayed monetary reward, with associated probability of being received, and a variable amount of immediate monetary reward delivered with certainty. Indifference points and demand curves are generated.
Delay Discounting Task	Choice between a larger fixed amount of delayed monetary reward and a systematically adjusted smaller monetary reward. Indifference points for different periods of delay are calculated and a discounting curve is generated
The Kirby	A 27-item questionnaire prompting choices between a larger, delayed amount of money and smaller, immediate amounts of money. Three indifference points are calculated.
Alcohol vs. Money Task; Cocaine vs. Money Task	Alternate methods of assessing delay discounting whereby the choice is between a substance and a monetary reward, rather than two varying monetary rewards. In both cases, indifference curves are generated and rates of discounting are calculated.