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REVIEW

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# Beyond discounting: possible experimental models of impulse control



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**Abstract** Animal studies of impulsivity have typically used one of three models: a delay of reward procedure, a differential reinforcement for low rate responding (DRL) procedure, or an autoshaping procedure. In each of these paradigms, we argue, measurement of impulsivity is implicitly or explicitly equated with the effect delay has on the value of reward. The steepness by which delay diminishes value (the temporal discount function) is treated as an index of impulsivity. In order to provide a better analog of human impulsivity, this model needs to be expanded to include the converse of impulsivity – self-control. Through mechanisms such as committing to long range interests before the onset of temptation, or through bundling individual choices into classes of choices that are made at once, human decision-making can often look far less myopic than single trial experiments predict. For people, impulsive behavior may be more often the result of the breakdown of self-control mechanisms than of steep discount functions. Existing animal models of self-control are discussed, and future directions are suggested for psychopharmacological research.

**Key words** Hyperbolic discounting · Impulsivity · Self-control · Reward bundling · Psychopharmacology

## Introduction

"Impulsivity" has been an imprecise construct in the clinical literature. Dozens of scales, sub-scales, and behavioral measures have been created to measure impulsivity, and the modest intercorrelations of many of these measures suggests different underlying conceptions of the construct (Corulla 1987; Parker et al. 1993). At the core of most if not all conceptions, though, is the notion of irrationality. In the animal literature, this irrationality manifests as failure to maximize overall reward. In human research, it is the individual's failure to follow her own recognized best interest. The word "recognized" is important; choices that a person consistently regards as desirable but which observers regard as maladaptive belong to a distinct category, for which we will not be using the name "impulsive."[1]

On this view, the study of impulsivity is a particularly challenging frontier for psychopharmacology. Understanding counterproductive behavior is straightforward when the culprit is misinformation. However, the thorny fact is that we repeatedly and wittingly subvert our own recognized long-term best interests. This utterly central aspect of the human condition defies conventional utility theory that attributes an ultimate rationality to all behavior. As typically defined, the construct of "impulsivity" is an acknowledgment of at least a subset of systematic irrationality.

Given the diversity of behaviors most often talked about in the context of impulsivity (including violence, gambling, credit card binges, sexual behavior, substance abuse, and self-injurious behaviors), the phenomenon cannot be understood as a product of a single appetite or a particular consumed substance. Instead, impulsive behavior must be related to the pattern of rewards available for certain behaviors. Even at the level of physiology, non-substance related addictive behaviors like gambling have been shown to look remarkably like substance-directed addictive behaviors (Wray 1981; Griffiths 1993; Comings et al. 1996; 1997). There is reason to believe that impulsiveness arises from the properties that re-

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[1] Dickman's typology of impulsivity distinguishes between "dysfunctional impulsivity" and "functional impulsivity" (which he defines as acting with little forethought when doing so is beneficial). While this explicitly allows for impulsivity to be rational, Dickman points out that 1) most work in the field focuses on dysfunctional impulsivity, and 2) that the two types of impulsivity are not highly correlated (Dickman 1990). As such, the inconsistency between "dysfunctional impulsivity" and the conception of impulsivity we are following lies mainly at the level of labeling

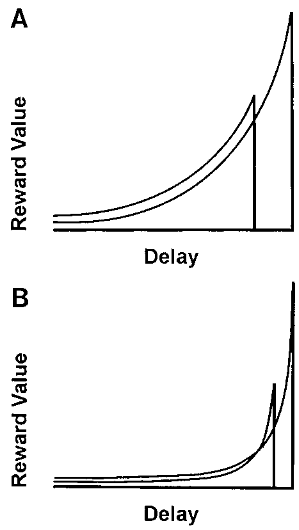


**Fig. 1** **a** Exponential discount curves from two rewards of different sizes available at different times. There is no delay at which preference switches. **b** Hyperbolic discount curves from two rewards of different sizes available at different times. The smaller reward is more valued just in the period when its availability is relatively immediate

wards behavior generally (Mazur et al. 1987; Shizgal and Conover 1996).

It has long been observed that the basic machinery of motivation favors more immediate reward. An organism, be it person or pigeon, will engage more readily in a behavior which immediately brings a positive outcome than one in which the same outcome occurs after a period of delay. The function relating the length of delay to the diminution in the motivating force of the reward is the temporal discount function. Some possible temporal discount functions are inconsistent with impulsivity. Exponential temporal discount functions (discounting by a fixed proportion per period of time) do not predict impulsive choice, regardless of how steep they are. An exponential discounter's temporal distance to a fixed set of alternatives will not affect the order of preference among those alternatives. The situation is like that of a set of savings bonds with different maturity dates and different denominations. Though both maturity dates and denomination will affect the current value of all the bonds, the relative value of the bonds will not change. The bond that has the greatest value at time T is certain to continue to have the greatest value at time T+X. For the same reason, if delay attenuates rewards by a fixed exponent, the reward that is most valued at delay T will also be the most valued at delay T+X (Fig. 1a). Temporal discounting at a fixed exponential rate, therefore, predicts stable preferences over time.

However, empirical research using a variety of organisms and a range of procedures has consistently found that temporal discount functions are not exponential, but rather hyperbolic (Ainslie 1975; Green et al. 1994; Harvey 1994; Kirby and Herrnstein 1995; Richards 1997). Discounting is steeper at short delays, and additional equal increments of delay produce progressively less additional discounting. Among other consequences, hyperbolic discounting predicts the motivational inconsistency over time that characterizes impulsive behavior. The relative value of two alternatives available at fixed times can switch, based solely on the addition or subtraction of an equal delay to both alternatives. For example, with the passage of time, the delay to fixed alternatives decreases by an equal amount. Given the form of the discount function, an alternative that was inferior from a distance may become preferred when its availability becomes immediate (Fig. 1b). Thus hyperbolic discounting leads to regular and systematic inconsistencies in preferences.

Particularly in the animal literature on the psychopharmacology of impulsivity, the concept of hyperbolic discounting has been widely used to model impulsive choice and track its pharmacological manipulation. In this article, we have three goals. First we will compare paradigms in the animal psychopharmacological literature on impulsive choice which do and do not use a temporal discounting framework. In doing so, we will argue that those that do not can and should be readily incorporated into such a framework. Second, we attempt to broaden the model by showing how, in addition to producing impulsivity, hyperbolic discounting can give rise to mechanisms of self-control. And third, with each mechanism we discuss animal models of self-control, and we suggest related directions for psychopharmacological research.

## Experimental paradigms of impulsivity

In the animal laboratory, studies of the impact of psychopharmacological interventions on impulsivity have variously used either a delay of reward paradigm (Charrier and Thiebot 1996; Evenden and Ryan 1996; Poulos et al. 1998; Tomie et al. 1998a), a DRL paradigm (Evenden 1998b; McMillen et al. 1998), or an autoshaping paradigm (Poling and Appel 1979; Picker et al. 1986; Tomie et al. 1998a, 1998b).

### Delay of reward

The delay of reward procedure is explicitly grounded in the temporal discounting conception of impulsivity. In this procedure, the organism chooses between two rewards – one larger but more delayed, the other smaller but more immediate. Impulsivity in the procedure is equated with the animal's tendency to choose the more immediate of the alternatives and in so doing, decrease the reward he receives. In an especially useful version of this, called the delay adjusting procedure (Mazur 1987), the delay associated with the larger reward is changed within session to determine the exact amount of delay necessary to make the larger alternative equally preferred to the more immediate alternative which remains fixed. If the animal repeatedly chooses the larger reward, the delay to the larger reward is increased; if the animal repeatedly chooses the smaller more immediate reward, the delay to the larger reward is decreased. When a criterion of stability is reached such that neither choice is clearly preferred, the parameters of the fixed and adjusting alternatives reveal an indifference point that indicates an equality between an additional delay and an additional quantity of reward. From an array of indifference points, the temporal discount function of the organism can be calculated.

The resulting function represents a radical departure from the exponential curve of conventional utility theory. The following simple hyperbolic function has generally provided a reasonably good fit to the data over a range of species and rewards (Mazur 1984; 1987):

$$V_d = \frac{V_i}{1+KD}$$

where $V_d$ equals the value of the delayed reward, $V_i$ equals the value of the reward if immediate, $D$ equals the delay, and $K$ equals a scaling constant which can be used as an index of discounting, and by extension, as an index of impulsivity. With data from human choices, this formula holds for time scales ranging from seconds to years (Solnick et al. 1980; Harvey 1994; Kirby and Herrnstein 1995). Importantly, while the form is consistently hyperbolic, the steepness of the discounting (the parameter $k$) varies enormously in human studies of choice. Most notably, the parameter $k$ can be smaller by orders of magnitude in human choice experiments with money as the reward (Ainslie and Haendel 1983; Green et al. 1994) as compared to when a primary reward is used such as the elimination of an aversive sound (Solnick et al. 1980; Navarick 1982). As we will argue below, the sophisticated strategies of self-control employed by humans can dramatically alter their observed discount functions.

Presumably because of practical limitations many pharmacological studies have not used Mazur's delay adjusting procedure which derives indifference points. Instead, choice alternatives are presented and the proportion of times the smaller more immediate alternative is chosen (over varying delays) is taken as an index of discounting (Evenden and Ryan 1996; Poulos et al. 1998; Tomie et al. 1998a). Although there are difficulties with the interpretation of these data, the underlying logic is unchanged. In these choice procedures, impulsivity is operationalized as the extent to which an organism will trade reward magnitude for reward immediacy.

## DRL

The second class of procedure used to measure impulsivity in the animal psychopharmacology literature is called DRL, "differential reinforcement of low rate responding". In this procedure an operant response is rewarded only if it occurs after a fixed interval of time has expired since the last response. Premature responses not only go unrewarded, but reset the expired time to zero, often after a salient brief time-out interval. Impulsivity here is equated to the extent to which an organism behaves prematurely, undermining its own attainment of reward. In recent times this procedure has also gone by a more descriptive name – "interresponse time greater than t" or "IRT>t" for short. One important variant on the procedure called the fixed consecutive number procedure (FCN) minimizes the confound between impulsive performance and general level of motor activity. In the FCN procedure, the animal has to make a required string of alternative operants (for instance pecking a green key) rather than wait out an interval before making the relevant operant (for instance pecking a red key). As in the DRL procedure, performing the operant associated with reward before satisfying the FCN criterion resets the counter and is not rewarded (Mechner and Latranyi 1963; Evenden 1998a).

## Autoshaping

A third type of procedure sometimes used in the animal literature on impulsivity is autoshaping. Autoshaped behaviors are those that organisms spontaneously engage in without obvious reinforcement. For example, if a key-light signals the impending arrival of food, a pigeon will come to peck at the key-light, even though doing so does not affect the arrival of food. The robustness of this seemingly unrewarded behavior is evident from a variant on the procedure called negative automaintenance. In a negative automaintenance procedure, the autoshaped behavior is punished by canceling the arrival of reward (Williams and Williams 1969). While autoshaped behaviors are diminished in the negative automaintenance procedure, they are usually not eliminated entirely (Schwartz and Williams 1972). The extent of autoshaped responding has been taken as a measure of impulsivity (Tomie et al. 1998a, 1998b). Given the common view of autoshaped behaviors as classically conditioned (elicited) responses rather than as operant (emitted) behaviors, this may seem a strange procedure to use for modeling impulsivity. However, autoshaped behaviors have also been argued to be completely operants (Dougan et al. 1983), or combinations of operant responses and Pavlovian responses(Schwartz et al. 1974).

## Delay equivalence

On the surface, delay of reward procedures seem to reflect one concept of impulsivity, and DRL and autoshaping procedures seem to reflect another concept of impulsivity. As Ho et al. succintly put it, "Research in the experimental analysis of behaviour suggests that two important characteristics of "impulsiveness" are i) deficient tolerance to delay of gratification [a steep temporal discount rate] and ii) inability to inhibit or delay voluntary behavior [poor inhibitory control];" (Ho et al. 1998, p.

68). Delay of reward procedures seem well suited to tap the temporal discount rate version of impulsivity, and DRL and autoshaping procedures (particularly the negative automaintenance variant) seem better suited to tap the inhibitory control version of impulsivity. However, on closer scrutiny, both DRL and autoshaping procedures lend themselves to a tolerance to delay interpretation in which poor performance amounts to the choice of a smaller but more immediate alternative. As such, the first of the two above characteristics alone (temporal discount rate) is sufficient to characterize impulsivity as it has been measured in the animal psychopharmacology literature.

In order to view poor performance on a DRL schedule as reflective of a steep underlying discount function, it is necessary to view premature responses as the choice of a smaller more immediate reward over a later larger one. This requires only the reasonable assumption that imperfect time sense makes the organism's estimate of reward vary as a function of delay. At the eighth second of a DRL10 trial, the organism may have what amounts to, say, a 50% expectancy of reward given an operant at that moment. Making the simplifying assumption of normative expected value, the reward availability for engaging in the operant after 8 s would in effect be 0.5 times the value of the reward when its availability is certain. The organism in effect has a choice after 8 s between an immediate 0.5*V, and a continuous range of later larger alternatives, such as, perhaps, 0.8*V after 2 more seconds, and 1.0*V a few seconds after that. A premature response amounts to choosing a smaller-sooner expected value over a later-larger expected value. As such DRL procedures do not necessitate the positing of any alternative or addition to the temporal discounting conception of impulsivity. This explanation does not account well for the burst responses often seen at the onset of DRL trials. However, at such time, when sunk cost is low, responses may be more like autoshaped responses (see below). On this view, prevalence of onset burst responding in particular ought to be inversely related to the inter-trial interval (ITI), since a long ITI will add to the animal's sunk cost.

The case of autoshaping requires further explanation, but we believe it also can be incorporated into the discounting framework, at least in the negative automaintenance variant. Again, the temporal discount rate conception of impulsivity requires viewing impulsivity as the choice of a smaller more immediate reward over a later larger alternative. Given a narrow definition of reward, autoshaped behavior has no measurable reward (and in the case of negative automaintenance, it has a measurable reward cost). As such, automaintenance behaviors have typically been treated as principally Pavlovian (elicited by the pairing with an unconditioned stimulus) rather than instrumental (emitted based on contingency of reinforcement). On a Pavlovian account, autoshaped behaviors and negative automaintenance behaviors could therefore not be viewed as the choice of a smaller more immediate reward since they are not choice behaviors at all.

However, we almost certainly make a mistake if we assume that all or even most of what rewards an organism's choice is observable. A person singing while in a state of joy may have no possibility of any externally observable reward. And yet the operant (reward driven) nature of that behavior is evident from the fact that its value is in competition with the value of observable rewards. The offer of money to refrain from singing, for instance, might be persuasive. Of course, if the sum of money was sufficiently modest, or the joy sufficiently intense, the observable reward could lose to the unobservable reward of singing. In the same way, pecking may be intrinsically rewarding for a pigeon that is anticipating food. The extension of this argument is an argument against two-factor theory generally. For the complete form, see Ainslie (1992 , pp. 102–122), Ainslie (1999) and John Donahoe's work suggesting a "Unified Reinforcement Principle" (Donahoe et al. 1993; Donahoe and Palmer 1994). This operant interpretation of autoshaping is consistent with the fact that the frequency and duration of the autoshaped response in negative maintenance procedures is greatly diminished, sometimes to the point of extinction (Woodruff and Williams 1976). Automaintenance behaviors can be understood as the choice of an immediate but possibly relatively small reward (the value of pecking when expecting food), over a more distant but larger reward (actual access to food). As such, changes in the frequency of these behaviors may reflect changes in the temporal discount function of the organism.

It is less clear to us whether autoshaping outside the negative automaintenance procedure can be reasonably taken as impulsivity as operationalized here. Since there is no apparent cost to the behavior, it is not clear that the animal engaging in autoshaped behaviors is trading off potential reward for immediacy. If "irrationality" is at the core of the concept being modeled, as we think it should be, then it is probably preferable to use procedures in which the presumed impulsive behavior has a more obvious cost. It is nevertheless interesting that individual differences in rats' sensitivity to delay on a delay of reward procedure were shown to be correlated with individual differences in the quantity of autoshaped behaviors performed (Tomie et al. 1998a).

Temporal discount rate seems to be the key underlying property in procedures used to model impulsivity. We believe that the delay of reward procedure is the best alternative as an animal model, since it alone allows the discount rate parameter $k$ to be directly estimated. The parameter $k$ can serve as an index of impulsivity, thereby allowing impulsivity to be quantified in absolute terms rather than having to be satisfied with relative comparisons.

## Mechanisms of self-control

Most of the interest in pharmacological manipulations of rats' impulsive behavior is based on the hope that the animal can serve as a useful model of human impulsivity. However, humans are capable of feats of self-control that look qualitatively different from the spontaneous behavior of rats. For instance, people often make financial decisions that are consistent with very low, exponential discount rates (Logue et al. 1986, 1993).

Since people and less cognitively sophisticated animals do not differ in the hyperbolic form of their discount curves, but differ greatly in their capacity for self-control, failures of this capacity are apt to come from a phenomenon not being measured in present psychopharmacology experiments. If we hope to manage impulsivity pharmacologically in people, then it makes sense to consider not just how hyperbolic discounting can produce impulsive choice, but also how normal adults manage to behave in farsighted ways. A person who is more impulsive than other people may not have a steeper underlying discount function, but instead may be impaired in whatever makes human choice farsighted. While surveys have often shown a general correlation between self-reported discount rates and impulsive behaviors, the most striking clinical observation is that individuals are markedly impulsive for a limited range of activities and for limited periods in their lives. Pharmacological interventions may affect mechanisms of self-control in addition to underlying discount functions.

A number of mechanisms of self-control are predicted by hyperbolic discounting. Since a person's preference among a fixed set of alternatives can vary predictably as a function of the passage of time, it follows that one of the obstacles they may face in trying to attain her current preferences is the expected preferences of their future selves. The dieter who has just finished bingeing has both a current clear preference for moderate consumption in the future, and an equally clear expectation that their own future self may pose a threat to this current preference. In order to secure what they currently want, it may be necessary for the person to find a way to precommit their future choices. They may, for example, precommit their future self to abstaining from savory snacks by ridding the kitchen of all such foods. Several distinguishable methods of precommitment have been identified (Ainslie 1975, 1992).

## Extrapsychic devices

The most direct method of precommitment is to arrange for some external control or influence – taking Antabuse, checking in to a "fat-farm", setting up a binding contract, or cultivating friends with particular expectations all can serve this role. The alcoholic who currently prefers not to get drunk later, but who doubts they will still feel that way when "later" arrives may stack the deck in favor of their current preference by taking Antabuse and adding the cost of nausea to a future self's decision to drink. The problem with extrapsychic devices is that they also reduce desirable flexibility, and may create a wasteful motive to try to evade or undo them.

The act of employing a mechanism to precommit against a future temptation may seem a sophisticated and exclusively human behavior. However, even pigeons sometimes precommit against a predictable preference reversal. One can easily establish parameters in a choice experiment in which pigeons will regularly peck a key that brings a smaller-sooner reward rather than wait for a later-larger reward. However, if given the option, some pigeons will learn to peck a key ahead of time which results in the removal of the smaller-sooner option from the choice set that will follow (Rachlin and Green 1972; Ainslie 1974). Thus a pigeon will make a binding precommitment to secure its current preference. It may be worth exploring whether some drugs increase or decrease the animal's learning of this response, quite apart from whether they change the impulsiveness that motivates it.

## Control of attention

Another method by which current preferences can guard against future changes of preference is by the control of attention. Someone struggling to maintain fidelity to a spouse may not allow themselves to notice the flirtations of an attractive third party. Attending to such information may foreseeably lead to the likelihood of creating preferences in opposition to current preferences. Attentional control can occur as either deliberate avoidance of information or an avoidance that is itself not acknowledged. The latter case is the repression that Freud at one time held to be the cornerstone of all defensive processes (Freud 1956). The repressive individual avoids unwanted thoughts, feelings or behaviors by not attending to the psychically loaded information. Aside from the distortions that Freud noted, its disadvantage is a loss of information that may be needed for other decisions.

A simplified animal model of impulse-control through manipulation of attention may be suggested by a recent experiment by Siegel and Rachlin (1995). In the experiment, pigeons were first exposed to an FR1 schedule with two reward alternatives in which the smaller more immediate reward was reliably chosen. Next, the reinforcement schedule was altered to an FR31 schedule which first required the pigeon to peck either of the two keys 30 times, after which he could then peck either key and attain the associated reward. In this schedule, the key chosen on the first 30 responses had no effect on reinforcement possibilities; the 31st peck alone determined which reward the pigeon received. In accordance with hyperbolic discounting, the larger more delayed reward was more valued from a distance. As such, it is not surprising that pigeons more often pecked the key associated with the larger reward during the first 30 responses. Importantly, more often than not the pigeons went on to peck the key associated with the larger more delayed reward even on the 31st trial which presented the exact same options as in the FR-1 condition. Though somewhat diminished, this shift away from impulsivity was still present when a one-second timeout signaled the onset of the 31st trial. This phenomenon, which the authors labeled "soft commitment"(Siegel and Rachlin 1995), may work by fixing the pigeon's attention on the alternative that is preferred at the start of a trial. On this account, enhanced performance is the result of a failure to shift attention to the alternative option. The interaction between "attentional set-shifting" (Owen et al. 1991) and impulsivity is of particular interest given the growing body of research reporting pharmacological manipulations that diminish attentional set-shifting performance (Coull et al. 1995) and manipulations that enhance attentional set-shifting performance (Roberts et al., 1994). Pharmacotherapies that diminish attentional set-shifting may increase the effectiveness of attentional manipulation as a mechanism of self-control since attention is made more permanent.

## Control of emotions

Emotions such as fear, jealousy, and arousal can, to a point be vicious circles. After the emotion has gotten underway, there is a lower threshold for further emotional activity of the same kind, until some satiation point is reached (Skinner 1953, pp. 235–236, 239–240). If a person expects an emotion to make currently unpreferred reward dominant, he may commit himself not to choose the reward through early inhibition of that emotion. There have been some experimental demonstrations of emotional control. For instance, Walter Mischel and colleagues found that while children below around 6 years were poor at self-control, many older children were often able to resist the temptation of an immediately available marshmallow in favor of a more preferred reward. Those that succeeded in avoiding the impulsive preference reversal often used emotional control in the form of thinking about the immediately available marshmallow in a "cool" way, or by imagining it to be undesirable (Mischel and Moore 1980; Mischel and Mischel 1983). Emotion-forestalling devices tend to distort rather than normalize motivation, and may make people emotionally unresponsive, as in alexithymia (Nemiah 1977). At the moment, there seems to be no way to analyze them using animal models.

## Choice bundling

The above mechanisms of self-control do not seem to match what people mean by "will-power"; they seem too mechanical. As William James (1890, p. 534) said, will-power seems to occur "with both alternatives steadily held in view." Hyperbolic discounting provides a mechanism for just such a method of self-control. Because the diminution of value is great with the addition of initial delay, but small with the addition of the same delay to an already far delayed alternative, it follows that the choice between alternatives will tend not to be impulsive if made far in advance. If a current choice is "bundled" with series of like future choices, and made at once, preference can be made less impulsive. Consider a smoker interested in quitting. Suppose that, for whatever reason, the smoker believed that his choice of whether to light up after breakfast would be a binding determinant of all future smoking choices; if he lit up he would continue smoking at the current rate for the rest of his life, but if he did not he would never smoke again. Presumably the aspiring former smoker in this situation would be more likely to refrain from smoking that one cigarette.

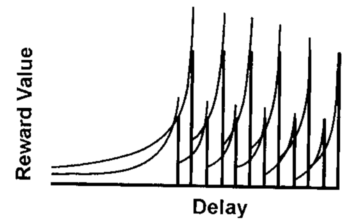


**Fig. 2** Summed hyperbolic discount functions for six pairs of rewards. As the number of future rewards being summed increases, the region of impulsive preference reversal is diminished

Such a decrease in impulsiveness when future choices are grouped with current choices is predicted by hyperbolic discounting. A single immediate reward that is more compelling than a larger but delayed alternative can be made relatively less compelling if both alternatives are summed over a series of identical future choices. The cigarette right now may be more valued than the expected beneficial consequences of abstaining from that cigarette, but each delayed cigarette may be less valued than the expected consequences of abstaining. If someone could bundle a series of these future cigarettes with the current cigarette she could tip the balance away from the impulsive choice (Fig. 2).

Hyperbolic discounting further predicts just such a possibility: A person's successive motivational states will be in a relationship of limited warfare with each other (Schelling 1960), sharing some goals, but at times in conflict over ones imminent when she makes each choice. This kind of conflict is stabilized by the perception that it is a variety of repeated prisoner's dilemma where the impulsive choice represents defection. The only way the present self can expect most future ones to cooperate is to make each choice a test case, so that current cooperation motivates future agents to preserve the chain of cooperation, and current defection destroys this future incentive. By seeing current choices as precedents for similar choices in the future, a person does arrange to choose between a whole series at once (Ainslie 1975, 1992, and forthcoming).

Although choice bundling has the advantage of not directly limiting freedom or information, it is far from a flawless solution to the problem of impulsivity. For one thing, it is precarious because it creates a motive for rationalization. The person faced with the possibility of immediate reward has a constantly present motivation to view the choice as singular. The prospect of (the immediate impulsive choice+an expectation of abstaining in the future), if credible, is better than either universal impulsive choice or universal abstinence. One consequence of this is the creation of a market for finding a reason that makes the current choice exceptional. As William James put it:

How many excuses does the drunkard find when each new temptation comes! It is a new brand of liquor which the interests of intellectual culture in such matters oblige him to test; moreover it is poured out and it is a sin to waste it; or others are drinking and it would be churlishness to refuse... or it is Christmas day; or it is a means of stimulating him to make a more powerful resolution in favor of abstinence than he has hitherto made; or it is just this once, and once does not count, etc., etc., ad libitum – it is, in fact, anything you like except being a drunkard (James 1890, p. 565).

Even when choices are bundled together successfully, the cure can be worse than the disease. Grouping choices increases the incentive against impulsivity, but in so doing, it also increases the costs of a single failure to resist temptation. Consistent with this, it has been demonstrated that among individuals who construct self-control rules which strictly group all members of a category (i.e. "I must never eat any sweets again"), lapses are less frequent, but more likely to turn into binge lapses of impulsive choice when they do occur. Interestingly, AA and other 12 step programs may have found a way to deal with some of the tension between the benefits and costs of choice grouping. By promoting the conception that the addict is helpless to have just one drink, the grouping implied is that one choice to drink will necessitate a whole binge of drinks. However, AA attempts to minimize the consequences of failure by advising resolutions for only "one day at a time" (Marlatt and Gordon 1980; Curry et al. 1987).

Another danger of choice bundling is that by valuing choices as precedents more than as events in themselves, choice-bundling can put the individual at risk for becoming rigid and legalistic. Obsessive-compulsive personality disorder (OCPD) and related everyday phenomena like workaholism can be viewed as pitfalls of extreme choice bundling. For example, a patient with OCPD may not use too large a postage stamp even once for fear that she will become a spendthrift. Furthermore, fear of lapses creates a motive to adopt highly explicit rules for oneself in preference to subtler ones that may be more richly rewarding (see Ainslie 1999).

The inadequacy of bundling as a route to true rationality creates a second kind of maladaptive choice, which has only partially been differentiated from impulsiveness in the literature of motivational science. While psychotherapists from Freud onward have recognized problems from "punitive superegos", "cognitive maps", "overgeneralization" etc. as distinct from spontaneous over-valuation of the immediate, our language still lumps together impulses like "compulsive spending" with rigidities like "compulsive saving", possibly because the latter has lacked a distinct recognized cause. However, the two are rather more like opposites. As Howard Rachlin put it, "The workaholic is less like the alcoholic than he is like the teetotaler. The workaholic's so-called addiction to work is really the compulsive avoidance of a narrow choice between work and leisure, a choice that by definition will always be resolved (if it is framed narrowly enough) in favor of leisure" (Rachlin 1995, p. 402).

The need for choice bundling suggests a second route to impulsivity, in addition to the steepness of the discount function. Impulsive behavior can occur because of the absence or breakdown of this rather brittle strategy. The underlying discount function might also interact with mechanisms of self-control. For instance, given a constant level of precommitment or choice-bundling across a set of individuals, it might still be the case that the individuals with the steeper underlying discount function will be more likely to exhibit breakdowns of self-control, and exhibit impulsivity. However, at the same time, the individual with the steeper discount function might also have a built-in motivation to precommit to non-impulsive behavior sooner, and also to employ more rigid rules for self-control. Unusually disciplined behavior might in some cases be the product of compensation for steep underlying discounting.

Of the two elements of choice-bundling (summation of serial rewards and perception of current choices as test cases) only the former has been shown in animals. Mazur showed that the value to pigeons of at least a small series of rewards was equal to the sum of the value of each reward individually (Mazur 1986). Thus it should follow that impulsivity is diminished in a delay of reward procedure in which single choices determines a series of rewards rather than a single presentation of the chosen reward. If experimental paradigms are created which can robustly demonstrate reductions in impulsivity based on reward summation, we may have an animal model of one element in a more sophisticated self-control mechanism. Psychopharmacological research can then look at how reward-summation responds to various manipulations. Those that facilitate summation in animal models should reduce impulsivity and those that undermine summation should increase impulsivity. We know of no work that has looked at pharmacological impact on the summation of serial rewards, an issue that is highly relevant to the study of self-control.

Thus far, the animal models of impulsivity used in pharmacological research have relied directly on phenomena that depend on hyperbolic discount functions. While we think this is the critical foundational element of impulsivity, animal models should be elaborated to include the converse of impulsivity – self-control. Relatively impulsive behavior in humans may be more a function of the extent to which mechanisms of self-control are employed than the steepness of the individual's underlying discount function. Mechanisms of self-control grow directly out of hyperbolic discounting, and in many cases can be modeled in animals. We think choice-bundling is a particularly critical mechanism of self control, and we are encouraged that the animal literature supports one of its properties – the summation of serial rewards. Clinical observation suggests that choice bundling may both precipitate impulsiveness by its failures, and impose another kind of maladaptive trait, compulsiveness, by its overgrowth. Pharmacologic research on impulsiveness should be done with these complex possibilities in mind.

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