Palpating the elephant: Current theories of addiction in light of hyperbolic delay discounting

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Many of the references of which I was author or co-author are downloadable from www.picoeconomics.org

Abstract
Addiction appears to contradict expected utility theory and has therefore been the subject of many re-examinations of motivation. Addiction is variously said to arise from and/or be maintained by conditioning, habit learning (as distinct from the goal-directed kind), the elicitation of counterfeit reward in the midbrain, accelerated delay discounting, hyperbolic delay discounting, and unspecified sorts of disease or compulsion that imply addiction is not motivated at all. Each of these models has some roots in observation but each has problems, particularly in accounting for addictions that do not need a neurophysiologically active agent, such as to gambling or video games. I propose that an implication of hyperbolic delay discounting—recursive self-prediction-- adds necessary mechanisms for addiction within a motivational framework. An addict's "force of habit" may be motivated by what amounts to accumulated consumption capital within an endogenous reward process. In a recursive motivational model the addict's impaired responsibility is more like bankruptcy than disease.

Keywords
Disease theory of addiction; dynamic inconsistency; expected utility theory; habit learning; hyperbolic delay discounting; impulsiveness; intertemporal bargaining; picoeconomics; recursive self-prediction; willpower

1. Introduction

The term addiction invokes the metaphor of enslavement, and is thus used to describe some force that overwhelms the other motives in a person's life. This force must be unwelcome; the term is not applied to spiritual rebirth, or an artist's devotion to her work. Since psychoactive substances are often at the root of such a force, observers often equate addiction with habituation to one of these substances—perhaps wishfully, since the possibility of being ensnared by the workings of your ordinary motivational apparatus is unsettling, to say the least. Nevertheless, this apparatus on its own can clearly generate overwhelming incentives that people report being unable to resist—to gamble, to shoplift, to seek escapist entertainment. Of course "resistibility" is not a hard datum, even with psychoactive substances, so addiction lies at the end of a continuum rather than forming a discrete entity. The important question is not the location of a boundary between addictions and bad habits, but how you can have robust motives for either that fail to equilibrate with your other motives.

In discussions of human decision-making addiction has been the elephant in the room, the phenomenon that contradicts economists' expected utility theory (EUT) and, analogously, behavioral psychologists' reward maximization, cognitive/social psychologists' goal pursuit (among others), and philosophers' rational choice with all things considered. Like the proverbial blind men we have come up with many models of this elephant: inborn susceptibility to some temptations, entrapment by the threat of withdrawal symptoms, weak will, aroused appetite ("hot thinking"), force of habit, deception by biochemical agents, and inconsistent evaluations of the future. These models get recruited to one side or the other of a debate as to whether people can be held responsible for their addictive choices, which is often framed as a question of whether addiction is a disease:

Disease: Addictive choices are involuntary, or compulsive in the sense of being beyond motivation. This is a frequent self-report by addicts. Writers have often cited William James' quotation from an alcoholic, "Were a keg of rum in one corner of a room and were a cannon constantly discharging balls between me and it, I could not refrain from passing before that cannon in order to get the rum" (James 1890, p. 543)[2]. Objectively, there is a wide range of evidence for genetic predispositions to develop most of the familiar addictions (Kreek et al. 2005) and for physical changes in addicts' brains (Goldstein and Volkow 2002).

Not a disease: Addictive choices are voluntary. Other writers have pointed out that consuming an addictive substance requires goal-directed and often quite sophisticated behavior, and furthermore that most addicts eventually stop this behavior on their own (Heyman 2009). Some writers have gone so far as to say that addictive behavior is a rational response to the reward offered by the activity in question, and that addicts differ from other

[2] Nick Heather has pointed out to me that James got the quotation from Benjamin Rush (1830). *Medical Inquiries and Observations upon the Diseases of the Mind.* 4th edition. John Grigg: Philadelphia, p. 264.

people only in their lower valuation of the future. Economists Gary Becker and Kevin Murphy famously claimed, "Addictions, even strong ones, are usually rational in the sense of involving forward-looking [utility] maximization with stable preferences" (Becker and Murphy 1988, p. 675). Researchers continue to make this claim, for instance Lemenze and Murray (2013).

As is often the case in longstanding debates, neither side is likely to have the whole truth. Addictive acts are clearly motivated—they don't take place in front of policemen, or, probably, cannons. Conversely, a failed wish to stop or limit these acts is part of their definition (APA, 2013). Unlike many real addicts, the rational addict of Becker and Murphy would not buy treatment to help her stop. In addiction the motive for the activity breaks free from the influence of its greater long term cost—but temporarily. If such a motive were continuous, that is, dominant at all times relative to when the choice was made, we would have to agree with Becker and Murphy that it was just a personal taste.

The basic question is: Why does someone repeatedly do something that she expects to regret? The answer that first comes to mind is that a chemical somehow tricks the brain; but if this is happening we still need to know how that trick translates into conflicted motivation. Furthermore, the existence of addictive patterns that do not involve a substance implies that addiction springs from something intrinsic to the way motivation operates, something that doesn't depend on being unlocked by a neurophysiological turnkey. Also, addicts commonly continue their behavior while reporting that the cigarette or drink or hit is no longer pleasurable. Thus three questions challenge EUT: why people are addicted, how we can become addicted to something nonphysical, and how addictive choices can become fixed so they persist after the pleasure is gone.

2. Parts of the elephant

Various mechanisms for addiction have been proposed. Some of them occur in everyone, raising the question of how they are different in addicts. None addresses addiction without physical reward, but I will make a suggestion about that (see Section 4.3). Several deal with the question of persistent activity without pleasure (Sections 2.2.5-6), but they have limitations that call for additional explanation.

2.1. Extra rewardingness

An inherited or acquired condition that makes an addictive activity extraordinarily rewarding may be a major factor in a person's loss of control over it. It is common for children of recovering alcoholics to grow up shielded from alcohol, then to plunge abruptly into heavy drinking as soon as they first experience it. A high degree of rewardingness may account for the power of an addiction, and discoveries of pharmacologic agents that block this rewardingness have sometimes led to effective controls, but rewardingness itself does not account for the conflictual nature of addiction—why addicts continue their activity while saying they want to stop. Steep devaluation of the future, itself hereditary (Anokhin et al. 2011), also makes fast-paying activities more differentially rewarding, but by itself also fails to account for their being conflictual.

2.2. Avoiding withdrawal

The first account of addiction with a physiological basis came from the common observation that addicts to many kinds of drug become tolerant of them and need increased consumption to attain a given effect, preparing the way for an increasing rebound by painful physiological "opponent processes" when the drug is stopped (Solomon and Corbit 1973). Addicts are said to then continue a relatively unrewarding consumption rather than face withdrawal symptoms, returning to consumption after the opponent processes have abated in turn (Ahmed and Koob 2005). But the opponent process pattern describes the arousal of appetites/emotions in general (Solomon and Corbit 1974). Although the threat of withdrawal may serve to prolong binges, some opiate addicts learn to endure and even induce withdrawal so as to cheapen their habits. Some substances, notably cocaine, do not induce physiological withdrawal; and some non-substance addictions do (Blaszczynski et al. 2008). Becoming trapped by the threat of withdrawal is not itself a sufficient explanation for addiction.

2.3. Weakness of will

A weak will has always been a folk explanation of addiction, and recent experiments on training the will have suggested it as a dimension to explore (Baumeister et al. 2006). It is a hard hypothesis to evaluate without details of how the will operates, but the observation that addicts often show intact willpower in other areas of their lives makes it doubtful as a general theory. I present a more specific hypothesis in Section 4.1.

2.4. Hot thinking

Decision-making during arousal of appetite is biased toward consumption, and has recently been studied as hot thinking (Kahneman 2011), which is accompanied by increased activity in the limbic and paralimbic brain areas (Bechara 2005)[3]. Arousal clearly increases motivation for addictive activities, but to evaluate its role in addiction its relationship to reward needs clarification. In particular, we need to look at whether arousal can be imposed on a person simply by association, or whether it depends on contingent reward.

Arousal of appetite is conventionally thought of as governed by classical conditioning rather than by differential reward: When a stimulus is regularly followed by a motivating experience it leads that experience to be anticipated. The first laboratory experiments on conditioning led to a theory that behaviors could be elicited in this fashion (for instance, clinking ice cubes leading to conditioned drinking), but careful controls revealed that only information (stimuli, perceptions) can be conditioned (Rescorla 1988), and any behaviors that occur are motivated by the resulting expectation (clinking ice cubes leading to an expectation of alcohol). However, it has never been clarified whether arousal of appetite should count as a behavior or, as often seems to be assumed, as part of a (conditioned) expectation. The distinction is important because expectations and behaviors operate differently. Expectations wane when not met. Behaviors depend on contingent reward, and thus might increase when an expectation is not met. "Conditioned" arousal that is said to incubate in the absence of new pairings, or which occurs to mere reminders that do not predict an unconditioned stimulus, is hard to explain unless it is a behavior.

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[3] Emotions such as anger and the thrill of gambling lack an external consumption good but otherwise behave like arousable appetites. I include them in the appetite category (see Ainslie 2001, pp. 65-69).

I have argued elsewhere that arousal of appetite is better seen as a behavior, one that is reward-dependent but mostly not deliberate (Ainslie 2010). Appetites could be thought of as foraging for possible rewards just as animals forage for food, and responding to available rewards more like your livestock than like your muscles. The Roman physician Galen already knew this, pointing out that anger was tamed like a horse, but that the "concupiscible power" (lust), like a wild boar or goat, had to be controlled by starvation (1963 p. 47). Galen would undoubtedly have counted the craving for hard drugs as a goat. This consideration should affect how we see the role of hot thinking in addiction, and is developed further in Sections.4.2-3.

2.5. Habit

Recent research into habit formation has led to the proposal that drug habits lose their responsiveness to motivation, thus continuing after they lose their pleasurable effects (Everitt and Robbins 2005). That is, addiction starts voluntarily but is hardened by repetition into something "automatic," beyond motivation. This proposal refers to a large body of recent human and nonhuman research on how behavior can be governed in two distinct systems: learning sequences of responses is "model-free," whereas the planning of choices is "model-based" (Balleine and Dickinson 1998). The two kinds of reward learning—habitual response sequences and planning models-- have been reported to be subtended at least in part by different areas of the brain—the unmapped (or model-free) habit system by the ventral striatum, and the model-based planning system by the ventromedial frontal lobes (Balleine and O'Doherty 2010). An animal that always finds food in one place stops looking around and simply repeats the movements that get it there, switching from its planning system to its habit system. Its moves can become so routine that they persist after the reward has been devalued, for instance by satiety (Yin and Knowlton 2004)—hence the suggestion that control by the habit system can be a model for addictions.

The overlearning effect is not peculiar to nonhuman animals. On my drive home from work city blocks become neighborhoods, neighborhoods become towns and the towns combine into a whole route, which unfolds without thought unless I interject a choice. The existence of a habit system that operates differently from a planning system is well established, but "mindless" would always have been a better term than "automatic" or "robotic" for the behaviors it governs. The latter terms imply an imperviousness to contrary motivation, whereas the habit system normally gives way to the planning system whenever a choice is subject to conflicting motives. Going out of my way to the grocery store requires only minor acts of vigilance, as does (probably) learning to find a new drug supplier. Addictive "habits" have very little to do with mindless repetition, but on the contrary require a high degree of flexible, goal-directed behavior to evade suppression by a hostile society. Furthermore, brain imaging that tracks whether a person is using model-based or model-free strategies to get rewards has shown that the supposed model-free center, the ventral striatum, is active during both (Daw et al. 2011). The two kinds of learning occur in parallel and are intimately connected: "Over the course of learning, behavior migrates from being goal-directed to being non-goal-directed" (Dayan 2009). The two systems interact from moment to moment: "People negotiate the trade-off between the two systems dynamically as a function of concurrent executive function demands," for instance when a distracting task is introduced or removed (Otto et al. 2013). Perhaps "the model-based system trains the model-free system by replaying and simulating experience" (Gershman et al. 2014).

However, this difficulty does not entirely dispose of habit as a mechanism for the maintenance of addiction. Proponents of habit as an explanation argue that addictive substances impair the brain functions that govern switching between the systems. Ablating the parts of a rat's brain that call up model-based choice may keep the rat from ever learning to respond to changed contingencies (Robbins and Everitt 2007). Analogously, patients who have had damage to their ventromedial prefrontal cortex do less well than normals on changed-contingency tasks, although the deficit has been reported to be only partial (Fellows and Farah 2005). The reported effects of addiction on such tasks have also been moderate, with one striking exception: cocaine addicts have been reported to perform markedly less well than non-addicts on changed contingency tasks, whereas amphetamine and opiate addicts do roughly as well as non-addicts (Ersche et al. 2008). Ersche and colleagues speculate that the surprising difference between cocaine and the pharmacologically similar amphetamines stems from cocaine's unique release of a related neurotransmitter, serotonin. Thus the habit hypothesis retains some merit for cocaine specifically, although we might still question whether impairment measured in seconds in a laboratory task implies inability to re-evaluate rewards and costs over the longer term.

2.6. Counterfeit reward

It has been suggested that some addictive substances create counterfeit reward in the brain—that is, they deceive you into expecting reward where none will be forthcoming. For instance, opiates have been said to "trick the system into believing that it has just received a strong reward, which it will learn to return to" (Redish et al. 2008). But if opiates function as rewards, they must *be* rewards, however unfortunate their long term results.

In a trickier suggestion of counterfeiting, dopaminergic agents such as cocaine can become "wanted" on the basis of their "incentive salience," an effect that may persist despite not being followed by a supposedly true reward, "liked" activation of the opiate system (Berridge and Kringelbach 2008). This effect has been produced in both nonhumans and human patients by stimulating the dopaminergic areas of their ventral striata. Once stimulation has started the subjects work vigorously to repeat it, but do not show facial signs (rats) or give reports (patients) of pleasure. Moreover the subjects often fail to start self-stimulation again once it has been stopped for a while. The areas of the midbrain that are involved are at least roughly the same as those that govern the habit (model-free) system. Evidence from local ablations in non-humans and dopaminergic neuron loss in Parkinsonian patients suggests that reward indeed has two separable components, wanting and liking. Liking does not lead to action unless wanting also occurs. The incentive salience that leads to wanting has been regarded as "nonhedonic" (Berridge 2003)--unrelated to reward; but I have argued that this divorce is unlikely (Ainslie 2009): The salience of a process must compete for your attention in the same currency as other rewards, and must therefore have a reward value itself. The sharp decline in the attractiveness of striatal stimulation with distance suggests that salience creates a very short term reward, something like an itch. Addictions seem also to lose their pleasurable component in this pattern: not a decline into frank aversiveness, but a decreasing duration of pleasure or relief—the smoker who lights cigarettes and then stubs them out, the opiate addict whose high turns stale rapidly, the overeater who must nibble repeatedly. In this vein, the old cartoon on my colleague's wall keeps drawing my attention despite no longer yielding pleasure. There may be many cases where a "wanting" component endures

while a "liking" component fades, and these may be related to the properties of different neurotransmitter systems. However, choice must still be determined by the final common selective factor of reward. The deterioration of pleasure into an itch-like pattern might well be regarded as a disease—we call eczema a disease, after all-- but scratching it is still a motivated behavior.

2.7. Hyperbolic delay discounting

Addiction is a predictable consequence of hyperbolic delay discounting, a universal trait. Humans have always lived on the edge of addiction. If the boundary of addiction is placed close to the "bad habit" range of the continuum, half the US population is reported to be addicted (Sussman et al. 2011). Those of us who have avoided the named addictive diagnoses are nevertheless apt to suffer from habitual overvaluation of the present moment, as in chronic procrastination (Andreou and White 2010), overuse of credit, or unrealistic future time commitment (Mullainathan and Shapir 2013). Theories of why this is so date back at least to the theological idea of original sin, and generally point to something innate in our makeup. An inborn hyperbolic delay discount function can explain both our predisposition to addictions and our repeated seeking of addictive agents when their mean pleasure value is negative. This proposal is converse to the others just reviewed—it reverses the figure and the ground, as it were. If a tendency to addiction is universal, the question must be how we mostly avoid addiction. Related questions are why this avoidance often fails, and why recovery is harder than avoiding the addiction in the first place. Also, by itself hyperbolic discounting does not account for nonphysical addictions. Nevertheless, I will suggest that hyperbolic delay discounting provides a framework for the other accounts of addiction.

3. Hyperbolic discounting in a nutshell

Hyperbolic discount functions describe temporary preferences for smaller, sooner (SS) rewards over larger, later (LL) rewards during the period when an SS reward is imminently available (formula 1, figure 1A); they also describe more preservation of value at long delays than do conventional, exponential discount functions, supporting a role for foresight in self-control (Ainslie 2001, 2005, 2012).

$$\text{Present value} = \text{Value}_0 / [1 + (k \times \text{Delay})] \qquad \text{Formula 1}$$

where Value_0 = value if immediate and k = degree of impatience (Mazur 1987).

However, the notion of hyperbolic delay discounting has been controversial, since it might be thought to have been heavily selected against in evolution. Also, it has not been found in some experiments (Montague et al. 2006), as well as in mature financial behavior, where an exponential discount curve is evident. These objections are answerable. As to the evolutionary objection, the attenuation of a perception in proportion to the intensity of the stimulus for it (the Weber-Fechner law) was a basic pattern in sensory domains long before species became engaged in intertemporal choice over periods of more than minutes. Before hominids evolved, animals did not plan for the future. Their farsighted behaviors were based on hardwired motives, to mate or migrate or defend territory, which pay off as the behavior is performed. Even in foraging, where it should be adaptive to weigh a distant food patch consistently against a present one, such consistency must not have been a strong selective

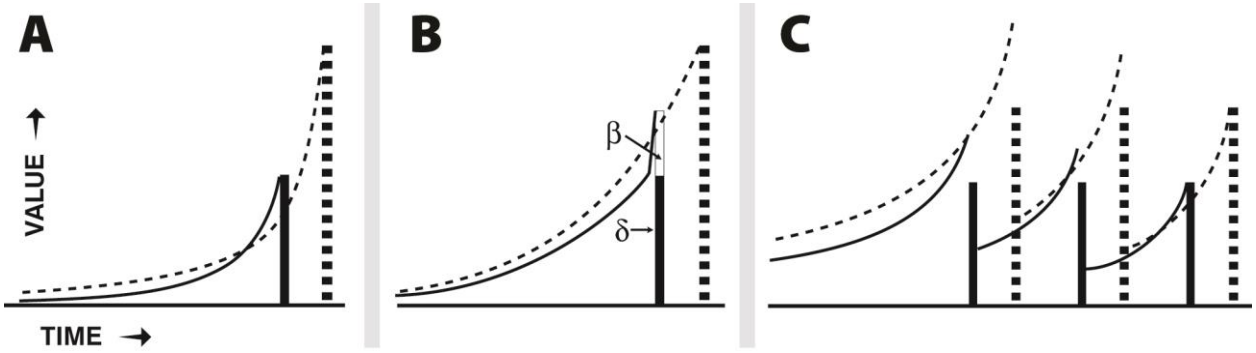
factor, since nonhuman animals do not show it (Kagel et al. 1986). Thus it is quite believable that the effect of delay on reward evolved within the constraint of the Weber-Fechner law, as a hyperbolic function (inverse proportion). As to people's sometime ability to make consistent choices over time between SS and LL rewards, the high tails of the hyperbolic discount curve describe an incentive that can lead self-aware individuals to approximate exponential curves (Ainslie 1991 and Section 4.1).

Despite these answers the hyperbolic discount function has been disruptive within behavioral science, particularly in economics (Montague et al. 2006; Ainslie 2012). A proposed compromise has been hyperboloid (quasi-hyperbolic) functions, conventional exponential discount curves with an extra curvature ("beta spike") that comes from the conditioned arousal of appetite/emotion just before the SS reward is due (formula 2, figure 1B):

$$\text{Present value} = \text{Value}_0 \times \beta \times \delta^{\text{Delay}} \qquad \text{Formula 2}$$

where Value_0 = value if immediate and β has one of only two values, $\beta = 1$ when reward is imminent or $0 < \beta < 1$ at all other times; $\delta = 1 -$ discount rate (McClure et al., 2004).

Figure 1



A. Hyperbolic discount curves from a single SS and LL reward. An early choice (near the left edge) would favor the LL reward, but a choice near the SS reward would favor the SS reward. B. Exponential discount curves from a "visceral" SS and a non-visceral LL reward. Just before the SS reward a beta spike would raise the effective value of the SS reward ("hyperboloid" discounting). C. Bundles of 3 choices as in A, made all at once: LL will be preferred at all choice points in advance of the first pair. Bundles of choices as in B would not yield this increase in LL choice.

Hyperboloid curves describe the day-to-day pattern of many addictions, but do not fit those temporarily preferred behaviors that don't entail arousal, such as procrastination; nor do they fit behaviors that unfold over longer time periods than arousal lasts, such as failure to save for the future, or that occur during time periods so short that preferences for SS and LL rewards both occur during arousal, as is the case with food deliveries to nonhumans with

differential delays of a few seconds (e.g. Ainslie and Monterosso 2003). Just as importantly, the beta spike does not raise the tails of the discount curves to the levels described by hyperbolas; thus hyperboloid curves do not account for the very low discount rates that subjects report over delays of decades (Cropper et al. 1992), or for the increased LL choice seen when choices are bundled together (figure 1C; Section 4.1). It may also be significant that a beta spike superimposed on otherwise exponential curves is inconsistent with proposed derivations of hyperbolic discounting from more basic phenomena, such as an aggregation of noisy delay estimates before each choice (Kurth-Nelson and Redish 2012). Therefore I have argued that the underlying discount function is purely hyperbolic, not a hyperboloid compound (Ainslie 2012). This is not to deny that aroused appetite is a factor in addiction, but I will argue that in humans it is governed by processes that follow from hyperbolic discounting, rather than being an exogenous factor imposed by association (see Sections 4.2-3).

The question remains of how people mostly manage to avoid addiction, and why failure to do so makes recovery difficult. Of course there are many ways that a society learns to keep the chance for addictive activities at a distance or to attach penalties to them. Beyond committing yourself to be influenced—or bound—by your society, there are ways you can physically commit yourself, keep your attention away from temptations, or build emotional resistance to them (reviewed in Ainslie 2001, pp. 73-78). However, the internal self-control that has become a major factor in modern societies hinges on recursive self-prediction.

4. Hyperbolic delay discounting motivates recursive self-prediction

Self-prediction is a familiar phenomenon in behaviors that are only marginally under voluntary control. You predict how they will develop by monitoring their current activity, and this prediction feeds back to change that development. Visceral processes such as anger, panic, nausea, sleep (in insomniacs), and urination (in men with prostatic hypertrophy) are accelerated by signs that they are already happening. Darwin famously proposed this phenomenon as a site of self-control:

> The free expression by outward signs of an emotion intensifies it. On the other hand, the repression, as far as this is possible, of all outward signs softens our emotions. He who gives way to violent gestures will increase his rage; he who does not control the signs of fear will experience fear in greater degree (Darwin 1872/1979, p. 366).

This observation led him, James, and Lange to mistakenly propose that physical reflexes *originated* such processes (Rolls 2005, pp. 26-28); but the processes are nevertheless *modulated* by the feedback that Darwin describes. The relevance to our topic is that hyperbolic discounting also reduces the sway of your current intentions over the future preferences you can expect to have, making self-prediction an important factor in many choices. Three patterns figure in human addiction.

4.1. Intertemporal bargaining creates willpower but also circumscribed failures

Hyperbolic discounting makes you uncertain that you will follow your own current intentions, creating an incentive for recursive self-prediction—a topic that I have called picoeconomics (micro-micro-economics; Ainslie 1992). To the extent that you notice how your current choice between an SS and LL reward predicts similar choices in the future, you create a bundle of expectations that depend at least somewhat on the current choice—and

which thus motivate that choice, as in figures 1C and 2A. Seeing your current choice as a test case creates a variant of repeated prisoner's dilemma with your expected future selves, and your moves in this game over time establish *personal rules* for when you will count a choice of SS as a defection (evidence reviewed in Ainslie 2012). Then the cost of eating a serving of a forbidden food, for instance, will only slightly be its effect on your weight or health, and will mostly be its damage to the credibility of your diet. I have presented evidence elsewhere that this example of recursive self-prediction is the central process of willpower (Ainslie 2001, 2005, 2012), although the name "willpower" is sometimes given to simple response inhibition that is achieved without weighing the alternatives[4]. Such *intertemporal bargaining* seems to be how people learn to achieve consistent choice over time despite an innate tendency to form temporary preferences for SS rewards. However, when this bargaining fails it may be a factor that not only permits but stabilizes addictions:

In personal rules the long tails of hyperbolic discount curves are effectively bundled together, creating increased incentive to choose LL rewards but also to evaluate choices in a legalistic manner. When choices are worth less in their own right than for the precedents they set, choice-making is removed from the here-and-now. In the extreme you may become entangled in your rules-- rigid, emotionally unengaged, compulsive. This development may be ultimately as undesirable as the impulses it targets[5].

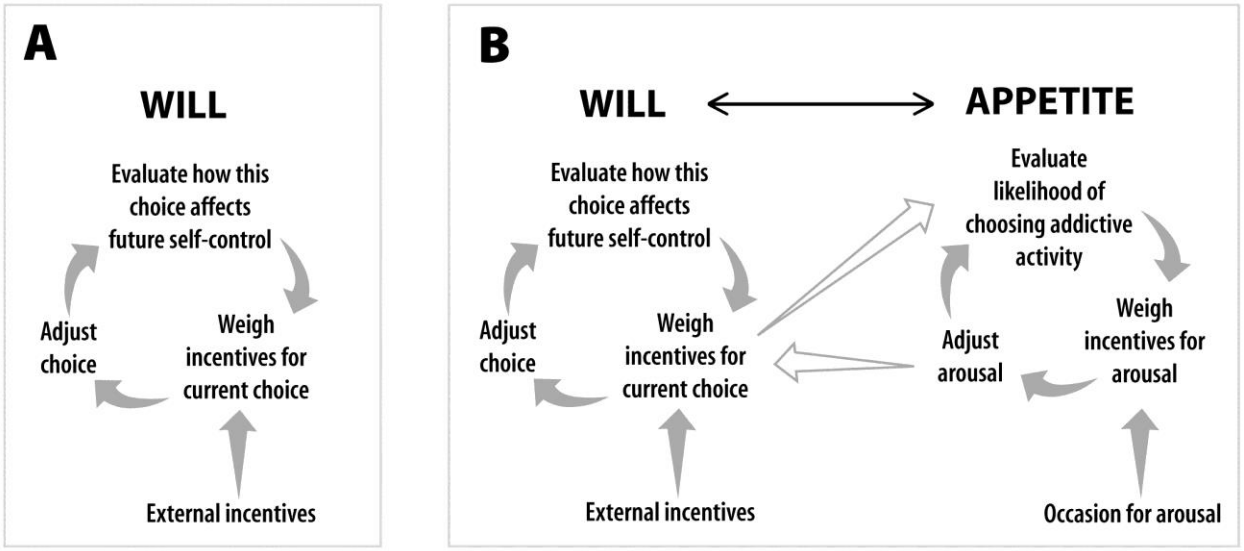
Addictions are not simply recurrent impulses, but complex compromises with your long term interests that develop when you try repeatedly to resist a temptation and fail. At first you may try to repair the damage to your expectation of self-control by seeing your lapse as a

[4] Response inhibition, as in go/no-go tasks, is clearly an unstable basis for resisting temptation over time, unlike a stake of substantial self-expectation against it. Response inhibition involves brain and neurotransmitter activity that is at least partially distinct from the activity that accompanies choice (Chambers et al. 2009; Luo et al. 2012). Unfortunately, many laboratory tasks designed to test the supposed muscle-like properties of will have mixed the two processes, by measuring subjects' willingness to continue response inhibition tasks (Kurzban et al. 2013).

[5] Compulsions should be distinguished from impulses and addictions. I recommend that "compulsive" be reserved for actions that are strictly confined by personal rules, rather than being overwhelmingly motivated in general, or even being beyond motivation, as when people talk about "compulsive drinking." Conversely, rule-bound, compulsive behavior is sometimes called addictive, as in workaholism, perfectionism, anorexia nervosa, and obsessive-compulsive personality disorder; but this usage is confusing, since the motivational dynamic is quite different-- overcontrol rather than failure of control. As a group, compulsive traits have much in common with each other and differ from substance- and thrill-based activities not only in their lack of arousal but in being more consistently preferred and integrated with your values (Ainslie 2009). Compulsions should not be called addictions or impulses, and vice versa.

special case (rationalization), by staking a wider set of expectations against this kind of lapse to create stronger resolve, or by simply repressing or denying the lapse. However, after repeated failures you have an incentive to protect the expectations upon which your will is based from further damage, by pulling back from attempts to control this kind of lapse. Thus a failure of will may stabilize an addiction by defining a sort of vice district where the law doesn't go. Your other endeavors may continue perfectly well, as has been the case with many figures who stayed productive despite an addiction (Coleridge, Halsted, Erdös); but your choices about where to attempt to use willpower create precedents that ramify as new situations arise. The resulting fabric of compromises creates a disincentive to attempt a radical change. Conversely, addiction in a binge pattern may protect personal rules by defining limited exceptions, for instance a resolution to be considerate, perfectionistic, and monogamous that goes into abeyance when "the alcohol is talking" (Ainslie 1999). The advice of the Anonymous organizations is to acknowledge the futility of intertemporal bargaining ploys with respect to the index temptation ("I am powerless over…"), a perception that actually serves to let an all-or-nothing stake of expectation grow gradually ("one day at a time") without being hedged by rationalizations. The advice to discern a higher power as taking part in your efforts may also offer strategic protection against the abstinence violation effect (discussed in Ainslie 2004). These are several rationales by which intertemporal bargaining may structure the complex relationships that people have with their addictions.

Figure 2



A. Recursive self-prediction in will. The effect of external incentives on preference is modified by how much you think your current choice will affect similar choices in the long run. B. Recursive self-prediction of your imminent arousal of appetite interacts with your recursive prediction, as in A, of whether your will is going to prevail in the long run. Arousal makes a lapse more likely, but more credible bundling of choices reduces the likelihood that arousal will lead to reward.

4.2. Sudden craving is a positive feedback phenomenon

Addicts often report that reminders of addictive activity, such as watching it on TV, have led to sudden craving followed by relapse into addiction (Stewart 2008). It is often said that such reminders are conditioned stimuli and are thus a logical target for therapy. But this kind of "conditioned craving" is not the same phenomenon that is observed in laboratory experiments. Mere reminders don't predict increased probability or immediacy of the event. By contrast, when smoker subjects are given cues that are sometimes followed by cigarette puffs, their arousal tracks the delay and probability of the puffs with great accuracy (Field and Duka 2001). But if reminders lead to sudden arousal in the absence of predictive information, how does it happen?

I have argued elsewhere that your consumption of an addictive good in real life is limited not so much by its physical availability as by your willingness to consume it (Ainslie 2010). Your entertainment of an appetite for the good is at least partially reward-dependent, and is often a rewarding activity itself, as witnessed by such entertainment being a venial sin for Catholics. Even when the arousal is not rewarding *per* se, it is rewarded when it brings about consumption of the addictive good. If you have made a personal rule against the activity and are not fully confident that you will obey it, you will be apt to see arousal of your appetite for it as a sign that you may give in, which would in turn be positively fed back to encourage the appetite (Figure 2B). If you are fully confident of obeying your rule, the appetite will stop arising, as has been reported to be the case with Orthodox Jews' craving for cigarettes on the Sabbath (Dar et al. 2005). A corollary, that sharp arousal of appetite by reminders should occur especially where willpower is strained-- as in controlled eaters or recovering smokers-- is empirically testable, but has not been tested.

In this view, arousal is reward-dependent, and thus a behavior. The rewards it depends on may or may not be external. Reminders serve as occasions for it. If craving is reward-dependent, rather than conditioned, a practical implication is that counter-conditioning treatments will fail, which is in fact the case (Conklin and Tiffany 2002). Furthermore, when we theorize that the cues associated with addictive activity are not drivers of reflex arousal, but signals of opportunities for appetites to challenge self-control, we are spared having to deal with two separate selective principles for components of addictive activities-- reward and classical conditioning, the latter having often been proposed as an explanatory *deus ex machina*.

4.3. Endogenous reward is the basis of non-substance addictions and the "force" of addictive habits

A fundamental property of human reward has been ignored in most motivational theories: sources of reward may grow in a person without relation to any hardwired source of value. Psychologists rarely talk about the roots of reward. When they do, they reveal a widespread assumption-- that reward has to come from events that are innately able to induce it. Events

that do not reward by themselves are said to be sought because they predict events that do, either by association or deduction ("secondary rewards;" see Baum 2005, pp. 77-86). This assumption makes some sense, since otherwise you might be able to reward yourself at will; but on the other hand it implies explanations of common motives that involve highly fanciful chains of association, chains that somehow do not extinguish despite years without their primary rewards. Behavioral science allows only occasionally for the possibility that the reward process often operates without being backed, as it were, by the hard currency of hardwired rewards—for instance in the recent goal setting literature that focuses on optimizing the risk of failure (e.g. Koch and Nafziger 2011). Such *endogenous* reward is distinguished from secondary reward only by being effective when it does not predict a primary reward—thus amounting to a primary reward in its own right, but one that lacks an innate inducing mechanism.

Hyperbolic delay discount functions suggest a rationale for how reward operates when it does not entail the prediction of innate inducers. To summarize a hypothesis developed elsewhere (Ainslie 2013a; an early formulation in Ainslie 1992, pp. 228-327): to get reward endogenously you just have to harvest it in imagination, but doing so at will makes it satiate quickly. To build appetite you have to define adequately infrequent *occasions* to claim the reward—make bets, ask questions, set up games. Appetite grows as it is hindered, becoming potentially more and more rewarding, but hyperbolic discount curves continually tempt you to harvest the appetite early. You will come to value those activities most where your appetite has grown large before harvesting, and to elaborate them into complex games that control an increasing potential for reward, forming in effect consumption capital (as used by Becker and Murphy 1988). The potential for reward that has so accumulated lacks a general name, but might be described as *hedonic importance*.

Occasions for endogenous reward need to be adequately *singular*-- not occurring so often that little appetite builds up-- and they need to be adequately surprising, since it is hard to keep attention from rushing ahead to a familiar occasion and harvesting some or all of its reward by anticipation. You are motivated to maintain the singularity of occasions by the same recursive logic that enforces personal rules: the problem with cheating at solitaire is that you lose your belief that future wins will be as rare as you have been expecting, and you thus undermine the hedonic importance of the game. Similarly, saying to yourself "it's only a game" when your sports team is losing reduces your capacity for joy when it wins. To ignore a bargain is to reduce the importance of finding bargains; to let an insult pass, or, in another context, to accept casual sex, is to reduce the importance of defending your honor; to act carelessly with your collection or hoard, is to cast doubt on its value. Most choices about hedonic importance are less explicit, but still of the form, "I find it important only if I expect to go on finding it important." Moreover, "the more I have found it important, the more important I now find it." What starts as a hobby may become the pursuit of a holy grail—sighting a rare bird or astronomical event, bringing off a risky shoplift, winning a professional prize, climbing Mount Everest (an extreme example in Leamer 1999). The value of each occasion depends on your expectation of continuing to value such occasions, just as the value of a fiat currency depends on the expectation that it will continue to be accepted.

The consumption capital represented by the hedonic importance of an activity gives it rewarding potential beyond its instrumental (practical) value. Crucially, the challenge of some instrumental accomplishments makes them singular, so they can accumulate hedonic importance on top of their instrumental value. This in turn creates incentive to preserve your belief in their instrumental value against evidence that it may have declined, since instrumental value is what *authenticates* the occasions that the task offers for endogenous reward. Thus hedonic goals come to parasitize instrumental ones. In the present context, you can learn to derive at least as much reward from the events of gambling *per se* as from the money you get from it—but only to the extent that you have built up its hedonic importance. The prize money is still indispensable, but increasingly for its role in making the gamble itself singular, rather than for how you might expect to spend it (discussed in Ainslie 2013b). The benchmark occasions of an addictive activity—winning the longshot, escaping with the goods, notching up the sexual conquest—produce endogenous reward just like the successes of more benign hobbies.

Similarly, the accumulation of hedonic importance may explain the persistence of a substance addiction after the substance has lost much of its own rewarding power. "Scoring" drugs does not just lead to the drug effect but also the occasion of a score like a score in hockey, which may stay effective when the drug itself has habituated. Smokers say they use cigarettes to mark significant moments in the day, and overeaters notoriously consume food on occasions when their actual appetite has waned. But even when the substance isn't pleasurable it is still necessary in order to authenticate the occasions for endogenous reward in its pursuit, just as a gambler needs real stakes even when resigned to eventual loss, and a kleptomaniac needs real thefts even of items she doesn't value. The structure of endogenous reward contingencies that serve as consumption capital is a likely explanation of the "force" of addictive habits, more so than is the kind of mindless habit that governs overlearned activities.

5. An intertemporal bargaining framework for addiction

Strikingly, none of the various proposals for explaining addiction contradicts any other one. Hyperbolic delay discounting suggests how they may all be part of the same elephant:

- Hyperbolic delay discounting creates a universal tendency to have temporary preferences for SS rewards.
- Inborn factors may make some of these rewards especially tempting, but if this increased preference were consistent rather than temporary we would call it a taste, not an addiction.
- Opponent physiological processes front-load our pleasures, so we seek them when close to them and then seek to defer withdrawal.
- The credibility of personal rules, which we summarize as willpower, is effective in reducing temporary preferences, but it is selective-- dependent on intertemporal bargaining history-- rather than being a general faculty. Both failed personal rules and overly strict personal rules create incentives to stop attempting self-control in some circumstances, thus stabilizing addictions.
- SS alternatives are strengthened by arousal of appetite, and strategies to get them may motivate this arousal recursively so as to overcome personal rules.

- Behavioral inflexibility—habit—may be partly a neurological consequence of long cocaine use specifically, but it is also apt to be motivated by the patterns of endogenous reward that grow in any highly engaging activity.
- Reward that is called counterfeit is actually just very short term, resulting in low average reward levels. Differential durability of dopaminergic connections may be a factor in why some or all addictions evolve shorter highs, but in any case this shortening can produce the itch-like experience of being compelled without having pleasure.
- To the extent that a pattern of stimuli is singular and surprising it may gather importance—hedonic capital-- by providing occasions for endogenous reward. Where this reward pattern has longer-term costs it may form a non-substance-based addiction. Endogenous reward may also add a non-substance component to substance-based addictions, fostering their persistence after the decline of substance-based pleasure. Strategies for getting endogenous reward also parasitize some instrumental activities to make use of the singularity of instrumental accomplishments, creating an incentive to misperceive some gambling-type activities as realistic.

Addictive behavior is clearly motivated; but some factors that affect motivation can be reasonably called diseases. I have argued here that the motivational patterns that are inconsistent with conventional EUT become consistent when EUT is modified to accommodate hyperbolic delay discounting; and that the process that emerges as crucial in addiction and recovery is recursive self-prediction.

In this view can we say that an addict is *unable* to resist temptation? Yes, if in her intertemporal bargaining she can see no way to bundle together enough motivation to stake against it. The factors that give short term rewards an edge might reasonably be called diseases, but the resourcelessness that follows her repeated defections in intertemporal bargaining is more like a budgetary crisis. When the addict can't find enough credibility to stake against her temptations to consume, we might say that she is no longer responsible for her choices—but because of bankruptcy, not sickness. An addict is not insensitive to differential motivation; her long range interests just cannot get adequate leverage. There is no natural test for whether such bankruptcy "exists" or not, nor even a test for when we should appeal to the concept. Such a concept would necessarily be culture-bound and would resist theoretical benchmarks, just as attempts to define legal insanity have done. And whereas the financially bankrupt cannot discover the funds they need by a radical restructuring of their books, addicts often discover how to re-frame their choices and suddenly regenerate their willpower (examples in Heyman 2009, 44–64). Responsibility in addiction will always be an elusive concept.

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