Comments on Mitchell

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Suzanne Mitchell's paper explores the hypothesis that the various factors that count as response costs can be described by a single, simple mathematical function. This is a novel and potentially powerful proposition. It suggests that quite different procedural operations, such as the length of the delay from response to reward or the force requirement for operating a lever, exact a common underlying bio-psychological effect. Mitchell's new experiments support her hypothesis, and given the idea's organizing power, it is likely that future studies will follow up where her new experiments and review leave off. However, in this response, I want to focus on a background issue that pertains to a subset of the studies that Mitchell discusses. In the delay discounting experiments, the quantitative relationship between delay and preference has proven the same in the various species that serve as subjects in psychological experiments. Pigeons, rats, and people discount the value of future rewards according to a simple hyperbolic equation. Moreover, as Mitchell's review emphasizes, laboratory-established differences in the parameters of this mathematical delay function predict important non-laboratory individual differences in behavior, such as drug use history. This finding implies that the delay procedure can be used to analyze individual differences that contribute to drug use and test new treatments. For instance, if a pharmacological or behavioral treatment decreased "impulsivity" in delay discounting experiments, it should also do so "on the street." However, the delay procedure findings are also quite puzzling, and the puzzle is in their generality.

The experiments that yield the same discount function for people and pigeons differ in ways that under other circumstances make a difference. In the human studies, the rewards are hypothetical and the subjects are not deprived, whereas in the animal studies, the subjects are deprived and the rewards provide essential and, in principle, life-saving sustenance. As these are motivational studies, these differences should matter, but they don't as measured by the shape of the function relating delay to choice. Why the same delay function applies to judgments that have but minor consequences and reinforced responses that have major consequences is the focus of the remainder of this paper.

Why Do Delays Decrease Preference?

The first point to make is that the effect of delay can be distinguished from the effect of a decrease in reward rate. For example, imagine the following study. In one condition, 10 seconds is added to a variable-interval 60 second schedule, and in a companion condition, variable

delays are added that have a mean of 10 seconds. Under both conditions the average inter-reinforcement interval is now 70 seconds, but in the second condition the added temporal increments are in the form of a delay (e.g. a blackout between the to-be-reinforced response and the reward). Although this exact experiment appears not to have been conducted, we can predict the results on the basis of similar existing studies (e.g. Chung 1965; Chung & Herrnstein 1967). In the rate condition, response rate will decrease as predicted by the matching law (Herrnstein 1970). For instance, if the experiment involved initially equal concurrent schedules, the decrease associated with the change in reward rate at one alternative would be less than 8% $(70/(70 + 60) - 60/(60 + 60))$. In contrast, in the delay condition, the decrease should be quite large, falling on a point predicted by a hyperbolic (multiplicative) discount function. Chung (1965) made a similar argument and shows in a graph (Figure 5) that the decreases in preference associated with a delay of reward are much greater than those associated with a decrease in reward rate (assuming matching). Indeed, if this were not the case then the preference reversals that are taken as evidence of hyperbolic discounting would not occur.

Thus, delay has a greater impact on preference than does a decrease in reward rate. Why? As is usually the case, we can imagine both a cognitive and a motivational explanation. The delay may weaken the association between responding and reward, thereby decreasing preference. Or the delay may function as a time-out from reinforcement, and time-outs reduce responding in much the same way as punishment. These interpretations are not mutually exclusive, and possibly there are other explanations as well. For instance, delay could be a fundamental parameter that influenced behavior even when the associative links were not weakened and the delay periods were arranged so that reward rates were not reduced. (Imagine an independent reward source that remains available during the delay period.)

Why Do Very Different Experimental Procedures for Measuring the Influence of Delay on Preference Produce Similar Results?

To better appreciate the relationships between method and results in delay discounting, it would be helpful to provide some details on the methods. Chung & Herrnstein (1967) were the first to clearly establish that delaying rewards decreased preference hyperbolically. Their procedure is no longer widely used (see papers by Mazur (2001) and Richards and his colleagues (1997) for more recent methodological developments). However, the relevant issue for the questions addressed in this paper is the range of conditions that promote a hyperbolic delay function, not the current state of animal research.

Food (grain) was the reinforcer. To ensure that the experimenter-arranged reward controlled behavior, the pigeons were put on a diet that reduced their body weight by about 20%. The amount of food earned during experimental sessions was not sufficient to maintain the 80% target weights so that after the experimental session, the birds were given supplementary servings of grain. The free food was eaten instantaneously, indicating that through the course of the session the birds remained ravenous. Thus, the experimental events were important, as measured by the subjects' welfare, and the subjects were, accordingly, highly motivated.

In the experimental chamber there were two buttons. Pecks on both were reinforced according to the passage of time. This was arranged by combining a concurrent variable-interval 60 second schedule with delay requirements. For instance, when a peck was eligible for reinforcement according to the interval timer, the reinforcer was withheld, and the chamber turned dark for a specified period of time. At the end of the blackout, the reinforcer was delivered and the chamber was re-illuminated. Chung & Herrnstein varied the blackout periods (delays) in the hope of determining the mathematical function that best described the relationship between the delays and preference. They found that an equation for a hyperbola did the best job. This result has been replicated numerous times, and as a result, the hyperbola is now widely accepted as the function that best describes the relationship between delay and preference.

Now consider what happens in the typical human study. The subjects are given a list of binary choices. One option describes a smaller amount of money available "now" and the other option describes a larger amount of money available "later," where later can mean an interval stretching from about a day to several years. However, "now" and "later" are in quotes because the rewards are either hypothetical or unlikely. In one version of this experiment, every question is hypothetical; the subject never gets what he or she chooses. For example, Myerson & Green (1995) asked subjects if they wanted $10,000 in 5 years or $6000 now, but the subjects in fact got nothing. In the second version of this procedure, one question from a list of about two dozen questions is selected at the end of the session, and the subject gets his or her choice on that question (e.g. Kirby & Marakovic 1995). For example, if by chance the third question on the list was selected, and on the third item the subject chose $2.00 "now," he or she would get $2.00 at the end of the session. However, for all other questions, the immediate choice could not be said to have precluded the delayed outcome, and vice versa. That is, the "reward" depends on the subject's ability or willingness to imagine receiving $2.00 at the end of the session or $3.00 a month from the end of the session.

Using some of the dimensions that were used to describe the pigeon experiment, it can be added that the subjects in the human studies were not deprived and that no consumption took place during the course of the experiment. It is reasonable to suppose that ingestion, metabolism, and satiation influence reinforcement processes, yet in the human studies the physical consequences of consumption are absent. Also note that delays did not include blackout periods, time-outs from reinforcement, or any factor that would influence associative learning. Finally, the delays in the human and pigeon experiments differ by several orders of magnitude. For the pigeons, 10 seconds was a long delay. In the human studies, subjects were asked to imagine rewards that will occur days, months, and even years into the future. Thus, in the animal experiments the rewards are palpable and matter, whereas in the human studies, the rewards are less palpable and by economic criteria, matter less.

Nevertheless, the results in the human studies follow in precise quantitative fashion the pattern predicted on the basis of the animal studies. Preferences for hypothetical monetary rewards were a hyperbolic function of the nominal delays, just as, in pigeons and rats, response rates were a hyperbolic function of the experienced delays. In other words, the shape of the mathematical function that joined judgments and imagined future events was the same as that which joined peck rates and peck-produced feedings. Moreover, drug users more often chose an imagined sooner, smaller reward than did non-drug users (see Mitchell), just as some pigeons were more impatient than others (see Ainslie 1974, 1975).

The usual research discrepancy is that similar procedures produce different results. But here, markedly different procedures produced similar results. There are either subtle but powerful methodological constraints that yield hyperbolic results regardless of the behavioral processes at hand or the procedures are tapping into highly general and robust bio-behavioral processes that play a critical role in animal and human decision-making.

Next are two possible explanations of why human judgments agree with pigeon peck rates. One includes the idea that human judgments about behavior are a veridical reflection of the behavior itself. The other is that behavior, even in the pigeon, has judgment-like properties, with response rates reflecting the value of the reward rather than the strength of the behavior. Most certainly there are other possible accounts, but these two seem the most obvious.

The data make sense if what people say about their preferences in the delay procedures accurately measures how they really behave, and how they behave is quite like how creatures like rats and pigeons behave. This statement involves at least three separable ideas: (1) that the questions regarding hypothetical monetary outcomes activate accurate representations of the quantitative features of past behavior and/or future behavior; (2) that the motivational impact of hypothetical monetary rewards is the same as the motivational impact of primary, consumable rewards like food and water; and (3) that the influence of delay on preference is the same for people and pigeons. These are testable assertions, and the delay literature suggests that there are conditions under which each is true.

Alternatively, human judgments of the value of delayed rewards and the actual behavioral effects of delayed rewards may converge because instrumental behaviors, such as lever presses, are in effect judgments as to the value of the contingent rewards. Put another way, conditioning studies are investigations of the psychophysics of reward, with response rate (on variable-interval schedules) standing as a proxy for sensations and the reward (say its frequency or magnitude) standing as a proxy for the stimulus. Hence, a pigeon's rate of pecking and a human's considered judgment about a hypothetical future event are both statements about the reward value of their respective eliciting stimuli. The competing view is that rewards strengthen or shape a particular response rate, as glue might reinforce a joint. But the strengthening interpretation makes it even harder to understand how reinforced response rates and human judgments can take a similar functional form.

There are two general solutions to the problems posed by this paper. The apparent similarity in the animal and human discount functions reflects similar underlying psychological processes, or, alternatively, the similarities are superficial, arising in quite different ways. To determine which conclusion is correct, the processes that mediate the behavioral level analyses need to be identified. A reasonable strategy would be to develop derivations of the hyperbola, test them in terms of their behavioral predictions, and then identify the attendant biological mechanisms. The second step would be sufficient to answer questions concerning whether the human and animal experiments were in fact revealing the same phenomenon, the third step tells us how nature engineers psychological processes, and the second and third steps together would increase our general understanding of preference for delayed rewards and could also have important clinical applications. Put more generally, as progress is made at the level of behavioral observation, it becomes increasingly important to understand the underlying psychological and biological processes.

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