Choosing delayed rewards: perspectives from learning theory, neurochemistry, and neuroanatomy

Reply to Bickel

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We thank Bickel for his kind comments on our article. We agree with him that identifying and characterizing the multiple processes contributing to choice is of fundamental importance to the understanding of disorders of choice such as impulsivity and drug addiction. Bickel makes the important point that one must also consider the interaction between reinforcers, as illustrated by the economic concept of cross-price elasticity, when considering choice involving multiple reinforcers, as is typical of real-world addiction.

Bickel comments on the theoretical implications of our finding that signals acting during a delay to reinforcement (putatively acting as conditioned reinforcers) interact with and alter the effects of psychostimulant drug administration. We commented in our article that this was a piece of evidence supporting the view that multiple processes contribute to the macroscopic phenomenon of delay discounting — the manner in which preference for a reward declines as it is progressively delayed. Bickel's point is that the presence of a putative conditioned reinforcer in our study (Cardinal *et al.* 2000) altered the effects of a psychostimulant drug on choice involving delayed reinforcement, but did not 'fundamentally alter (the) functional relationship' between delay and choice.

It is clear that a subject's tendency to choose a particular delayed reinforcer depends not only upon the delay, but also upon the presence or absence of a signal during that delay (and that, if administered, psychostimulants also affect choice, and can interact with the delay and with any signal present). The delay and the signal both contribute to observable behaviour. Thus, we feel it is accurate to assert that this is an example of observed behaviour — described as discounting — depending upon the effects of at least two processes.

Bickel is quite right to point out that it has not been established that conditioned reinforcement is responsible for part of the effects of the delay itself, and our study did not do so — as delays unmistakably affect choice even when they are unsignalled, the effects of signals present during the delay must be to some degree separable from the effects of the delay itself. Nor has it been clearly established whether signals present during the delay have effects that interact linearly with those of the delay, or interact nonlinearly (we presume the latter is what Bickel refers to when he speaks of a 'fundamental alteration' in the relationship between delay and choice).

However, we feel that an overemphasis on the idea that 'delays' and 'cues' are themselves *represented by neural processes* may be misleading. Instead, they are clearly variables that affect several processes. It has never been proven that the effects of a delay are computed by a single neural process, providing a value that may be combined with other values (of reward magnitude, probability, etc.) to allow the reinforcer with the

highest value to be selected in standard utility-theory fashion, as the term 'delay discounting' may itself suggest. On the other hand, it has been shown, independently of experiments involving delayed reinforcement, that animals are influenced by several clearly separable processes when working for reinforcement (reviewed by Cardinal *et al.* 2002). These include the instrumental contingency between actions and outcomes, the instrumental incentive value of the reinforcer (most closely analogous to 'value' as conceptualized by traditional utility theorists), cue-induced Pavlovian motivational processes, habits, and so forth. Some of these processes have been proven to be affected by delays to reinforcement. For example, delays impair instrumental action–outcome contingency learning (Dickinson *et al.* 1992), and very probably reduce the incentive value of delayed rewards. Therefore, as there is excellent evidence that the selection of non-delayed reinforcers is governed by multiple processes, and delays can affect at least some of these processes, we feel the analysis of choice among delayed reinforcers should take account of these multiple processes from the outset.

References

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