Behavioural Processes 127 (2016) 62–73

Contents lists available at ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

A model for discriminating reinforcers in time and space

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ARTICLE INFO

Article history:
Received 18 November 2015
Received in revised form 7 March 2016
Accepted 17 March 2016
Available online 22 March 2016

Keywords:
Discrimination
Timing
Model
Choice
Stimulus control

ABSTRACT

Both the response-reinforcer and stimulus-reinforcer relation are important in discrimination learning; differential responding requires a minimum of two discriminably-different stimuli and two discriminably-different associated contingencies of reinforcement. When elapsed time is a discriminative stimulus for the likely availability of a reinforcer, choice over time may be modeled by an extension of the Davison and Nevin (1999) model that assumes that local choice strictly matches the *effective* local reinforcer ratio. The effective local reinforcer ratio may differ from the obtained local reinforcer ratio for two reasons: Because the animal inaccurately estimates times associated with obtained reinforcers, and thus incorrectly discriminates the stimulus-reinforcer relation across time; and because of error in discriminating the response-reinforcer relation. In choice-based timing tasks, the two responses are usually highly discriminable, and so the larger contributor to differences between the effective and obtained reinforcer ratio is error in discriminating the stimulus-reinforcer relation. Such error may be modeled either by redistributing the numbers of reinforcers obtained at each time across surrounding times, or by redistributing the *ratio* of reinforcers obtained at each time in the same way. We assessed the extent to which these two approaches to modeling discrimination of the stimulus-reinforcer relation could account for choice in a range of temporal-discrimination procedures. The version of the model that redistributed numbers of reinforcers accounted for more variance in the data. Further, this version provides an explanation for shifts in the point of subjective equality that occur as a result of changes in the local reinforcer rate. The inclusion of a parameter reflecting error in discriminating the response-reinforcer relation enhanced the ability of each version of the model to describe data. The ability of this class of model to account for a range of data suggests that timing, like other conditional discriminations, is choice under the joint discriminative control of elapsed time and differential reinforcement. Understanding the role of differential reinforcement is therefore critical to understanding control by elapsed time.

Contents

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http://dx.doi.org/10.1016/j.beproc.2016.03.010
0376-6357/

Differential responding requires a minimum of two discriminably-different stimuli and two discriminably-different contingencies of reinforcement (Nevin, 1981). Responding is maximally differential when both stimuli and reinforcers are maximally differential. When the stimuli are made more similar, or when the reinforcer differential is made smaller, responding becomes less differential – that is, changes in the stimuli and in the reinforcers produce similar changes in behavior. Therefore, performance on a discrimination task depends on the extent to which both the stimulus-reinforcer and response-reinforcer relations are discriminated accurately.

Davison and Nevin (1999) proposed that the effect of the arranged contingency on responding depends on the extent to which this contingency is correctly discriminated, because choice strict matches the *effective* contingency. Imperfect discrimination produces a difference between the arranged contingency and the effective contingency discriminated by the organism. The poorer the discrimination, the greater the difference, and therefore the weaker the control of behavior by the arranged contingency.

In a simple conditional discrimination task arranged for pigeon subjects, responses to one key (B_1) are reinforced in the presence of, or following, one stimulus (S_1), and responses to another key (B_2) are reinforced in the presence of, or following, another stimulus (S_2). The contingencies arranged in such a task are specified in the matrix in Fig. 1. Confusion as to the response that produced a reinforcer – error in discriminating the response-reinforcer relation – may be modeled by shifting reinforcers between the left and right columns of the matrix. Confusion between S_1 and S_2, and thus imperfect discrimination of the stimulus-reinforcer relation, may be modeled by shifting reinforcers between the upper and lower rows of the matrix. In this way, Davison and Nevin's (1999) model proposes that the effects of each reinforcer generalize to other responses and other stimuli, to the extent that those other responses and stimuli are confusable with the response and stimulus associated with that reinforcer.

While the study of discrimination learning usually uses exteroceptive stimuli such as colors, lights, tones or spatial locations, discrimination of interoceptive stimuli such as duration appears to be affected by similar factors (e.g., Davison and McCarthy, 1987; Sargisson and White, 2001). Although all these stimuli are usually deployed so that they are discretely different, they are in fact part of a continuous distribution of wavelength, light intensity, sound, space, or time. Thus, although Davison and Nevin's (1999) approach was developed to describe conditional discrimination between discrete stimuli, there is no reason to assume that the processes that underlie discrete-stimulus discrimination learning are not germane to continuous-stimulus discrimination learning.

Even so, discrimination between continuously changing stimuli is often assumed to be subject to processes separate from those underlying discrimination of discretely different stimuli. Perhaps the most salient example of this is the study of temporal-discrimination learning, or interval timing. Error in temporal-discrimination tasks is typically described as a failure to discriminate the stimulus, elapsed time since some marker event, rather than as a failure to discriminate the relation between stimuli, responses and reinforcers (e.g., Scalar Expectancy Theory, Gibbon, 1977; Behavioral Theory of Timing, Killeen and Fetterman, 1988; Learning to Time, Machado, 1997; Behavioral Economic Model, Jozefowiez et al., 2005). However, if discrimination of discrete and continuous stimuli depends on the same underlying processes, responding in a temporal discrimination task might be better described in terms of the discriminability of the stimulus-reinforcer and response reinforcer relations, rather than in terms of the discriminability of the temporal stimuli alone.

The free-operant psychophysical procedure (FOPP; Stubbs, 1980) for studying timing is a simple example of a choice-based discrimination procedure where the likely availability of a reinforcer is signaled by elapsed time since an event. In the FOPP, responses to the left key (B_1) produce reinforcers on a variable-interval (VI) schedule during the first half of a trial (S_1), and responses to the right key (B_2) produce reinforcers on a VI schedule in the second half of a trial (S_2). The arranged contingency in the FOPP may be summarized in a matrix (Fig. 2) similar to the one used to describe the contingency in a standard yes-no signal detection task (Fig. 1). Such an approach implies that discriminating the contingencies of reinforcement in the FOPP depends on two factors: Discrimination of the response that produced each reinforcer, and discrimination of the time at which each reinforcer was obtained.

Accordingly, one source of error in discrimination might arise because reinforcers for one response are discriminated to have been produced by the other response. This sort of error would result in an apparent shift of some of the obtained reinforcers between the left and right columns of the matrix in Fig. 2. Where two responses are available, reinforcers may be allocated to one of two columns in the matrix. Thus, error in discriminating the response that produced a

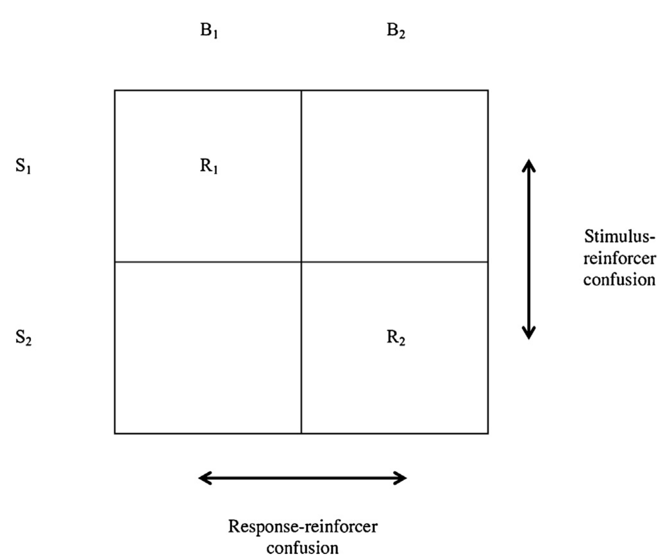

Fig. 1. Matrix describing the contingencies arranged for a typical discrete-stimulus discrimination task, for example the yes-no signal-detection procedure.

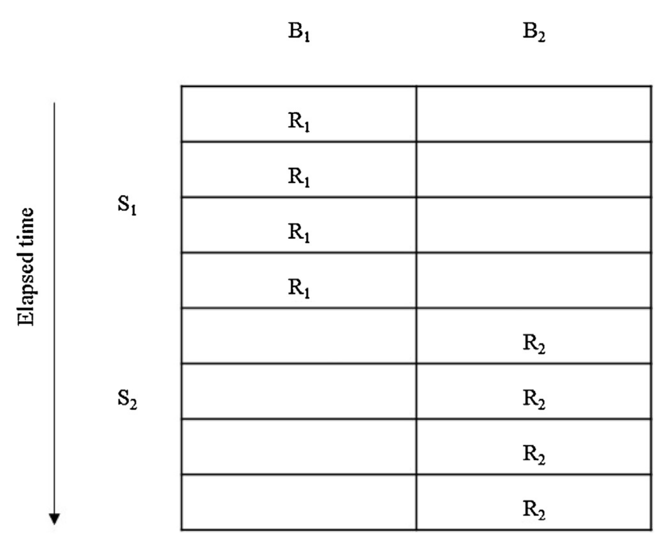

Fig. 2. Matrix describing the contingencies arranged for the free-operant psychophysical procedure for studying temporal discrimination.