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Reinforcer distributions affect timing in the free-operant psychophysical choice procedure☆

Sarah Cowie[a,*], Lewis A. Bizo[b], K. Geoffrey White[c]

[a] University of Auckland, New Zealand
[b] University of New England, Australia
[c] University of Otago, New Zealand

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ABSTRACT

In procedures used to study timing behavior, the availability of reinforcement changes according to time since an event. Manipulation of this reinforcer differential often produces violations of scalar timing, but it is unclear whether such effects arise because of a response bias or a change in temporal discrimination. The present experiment investigated the effects of the overall and relative probability of obtaining a reinforcer on performance in the free-operant psychophysical procedure. We arranged short and long trials with unequal reinforcer ratios, at high or low overall reinforcer rates. Changes in the overall reinforcer rate produced only small changes in timing behavior. Changes in relative reinforcer probability, which caused differences in the likely availability of reinforcers across time within a trial, produced a change in both bias and discrimination. We suggest reinforcers affect timing, and that discrimination in timing tasks depends on the distribution of reinforcers in time, as well as on the interval to be timed.

1. Introduction

The effect of reinforcers on performance in interval timing tasks appears to extend beyond the reinforcer's function as a marker event. While these effects are evident in a range of different temporal-discrimination procedures (e.g., Bizo & White, 1994a,b, 1995; Doughty & Richards, 2002; Galtress & Kirkpatrick, 2009), they are particularly salient in the free-operant psychophysical procedure (FOPP; Stubbs, 1980) for studying immediate timing. In the FOPP, a two-key concurrent variable-interval (VI) extinction (EXT) schedule operates for the first half of each trial (with VI on the left and EXT on the right), reversing to a concurrent EXT VI schedule for the second half of each trial (with EXT on the left and VI on the right), as illustrated in Fig. 1. There is no exteroceptive discriminative stimulus to signal the transition from first to second halves of a trial. The likely availability of reinforcement in the first versus second half of a trial is therefore signaled by time since the beginning of the trial. Unlike procedures in which the likely availability of a reinforcer is signaled by a specific time interval, as in the peak procedure (e.g., Beam, Killeen, Bizo, & Fetterman, 1998), timing in the FOPP involves discrimination of when reinforcers are likely to be obtained for each of two responses. Thus, the FOPP permits the investigation of how both relative and absolute properties of reinforcers affect temporal-discrimination performance, independent of variations in the duration to be timed.

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* Corresponding author at: Department of Psychology, University of Auckland, Private Bag 92019 Auckland, New Zealand.
E-mail address: sarah.cowie@auckland.ac.nz (S. Cowie).

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The psychometric function generated from responding on the FOPP relates responses made on one alternative (the right key in the present experiment) as a proportion of responses made on both alternatives (left and right keys) to time elapsed since trial onset (e.g., Bizo & White, 1994a, 1994b; Stubbs, 1980). In the procedure illustrated in Fig. 1, the pigeon typically responds on the left key at the beginning of the trial, and so the proportion of right responses is close to zero. As the trial continues, responding increasingly shifts to the right key and the proportion of right responses shows a sigmoidal increase as a function of time in the trial. Psychometric functions may differ in slope, or in their positioning along the time-since-trial-onset axis. A change in the slope of the function implies a change in accuracy of timing. A shift in the positioning of the function could imply a preference for left- versus right-response keys independently of a change in timing accuracy; that is, a response bias. It could also imply a change in the discrimination of the transition between reinforcement probabilities in first versus second halves of a trial occurring too soon or too late, that is, a bias towards right-key responding sooner or later.

In the absence of changes in the duration to be timed, differences in the psychometric function may be produced by variations in overall reinforcer rate (Bizo & White, 1994a, 1994b), as well as by changes in the ratio of reinforcers for responding at different halves of a trial (Bizo & White, 1995). Increases in the overall reinforcer rate appear to produce steeper psychometric functions, suggesting that overall reinforcer rate affects timing. In contrast, variations in the relative reinforcer rate appear to produce shifts in the positioning of the function consistent with a bias toward the response alternative associated with the relatively higher probability of reinforcement, as in standard concurrent choice procedures (e.g., Davison & McCarthy, 1987; Raslear, 1985; Stubbs, 1968). Such a bias is time-dependent, but independent of a change in discrimination. Similar shifts may also be achieved by varying the reinforcer rate in each quarter of a trial, but holding the overall reinforcer rate in the first- and second-half equal (Machado & Guilhardi, 2000). Thus, reinforcers may affect both the timing and decision-making component of temporal-discrimination tasks.

The exact process underlying these effects of reinforcers remains unclear. Theories of timing attribute these effects of reinforcers on temporal discrimination performance to a variety of mechanisms. The Behavioral Theory of Timing (BeT; Killeen & Fetterman, 1988; Fetterman and Killeen (1991)) assumes that the speed of a hypothetical pacemaker varies directly with overall reinforcer density. Thus, BeT predicts that increases in the overall reinforcer rate produce a change in timing, such that subjective time passes more quickly. Although differences in the relative reinforcer rate do not alter the overall reinforcer density, pacemaker period may be made sensitive to the effects of relative reinforcer rate by assuming that unequal relative rates bias the pacemaker (see Bizo & White, 1995). However, this relation between pacemaker period and relative rate cannot account for changes in psychometric functions that arise when rates differ across quarters, but not halves, of a FOPP trial (e.g., Machado & Guilhardi, 2000).

Learning to Time (LeT; Machado, 1997), a derivative of BeT, also predicts that the overall reinforcer rate controls the speed at which the animal moves through subjective time. According to LeT, a pacemaker controls the speed with which different states become active, and reinforcers obtained while a state is active increase the probability of that response being emitted while the state is active in the future. LeT thus interprets the effects of unequal reinforcer distributions across halves or quarters of a trial as the result of a bias toward emitting a particular response at a given time.

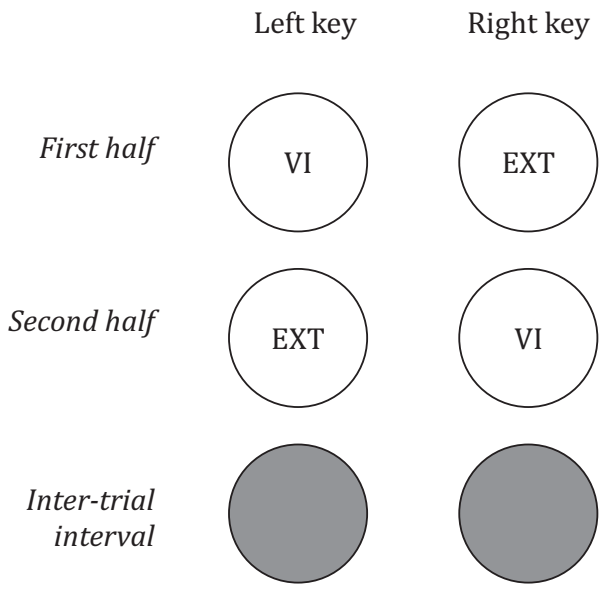

Fig. 1. Diagram of the free-operant psychophysical procedure. The concurrent VI Ext schedule on left and right keys in the first half of the trial is reversed for the second half of the trial. Trial halves are discriminated by time since trial onset and not by an exteroceptive stimulus.