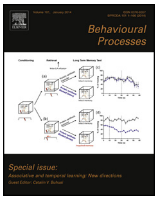
Behavioural Processes 101 (2014) 23–31

Contents lists available at ScienceDirect

Behavioural Processes

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



Separation of time-based and trial-based accounts of the partial reinforcement extinction effect

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ARTICLE INFO

Article history:
Received 28 January 2013
Received in revised form 26 June 2013
Accepted 6 August 2013

Keywords:
Extinction
Partial reinforcement extinction effect
Associative models
Timing models

ABSTRACT

Two appetitive conditioning experiments with rats examined time-based and trial-based accounts of the partial reinforcement extinction effect (PREE). In the PREE, the loss of responding that occurs in extinction is slower when the conditioned stimulus (CS) has been paired with a reinforcer on some of its presentations (partially reinforced) instead of every presentation (continuously reinforced). According to a time-based or "time-accumulation" view (e.g., Gallistel and Gibbon, 2000), the PREE occurs because the organism has learned in partial reinforcement to expect the reinforcer after a larger amount of time has accumulated in the CS over trials. In contrast, according to a trial-based view (e.g., Capaldi, 1967), the PREE occurs because the organism has learned in partial reinforcement to expect the reinforcer after a larger number of CS presentations. Experiment 1 used a procedure that equated partially and continuously reinforced groups on their expected times to reinforcement during conditioning. A PREE was still observed. Experiment 2 then used an extinction procedure that allowed time in the CS and the number of trials to accumulate differentially through extinction. The PREE was still evident when responding was examined as a function of expected time units to the reinforcer, but was eliminated when responding was examined as a function of expected trial units to the reinforcer. There was no evidence that the animal responded according to the ratio of time accumulated during the CS in extinction over the time in the CS expected before the reinforcer. The results thus favor a trial-based account over a time-based account of extinction and the PREE.

This article is part of a Special Issue entitled: Associative and Temporal Learning.

1. Introduction

Behavioral models of Pavlovian learning have traditionally assumed that the conditioning trial, or the occasion on which a conditioned stimulus (CS) is presented, is the basic event that enables associative learning (e.g., Mackintosh, 1975; Pearce, 1994; Pearce and Hall, 1980; Rescorla and Wagner, 1972; Wagner, 1981, 2003; Wagner and Brandon, 1989). Such "trial-based" models differ in many details, but commonly assume that trials on which the CS is paired with the unconditioned stimulus (US) can increase associative strength whereas trials on which the CS occurs without the US can either decrease associative strength or cause inhibition to be learned. The models have been highly successful at explaining and anticipating the outcomes of large number of conditioning experiments (e.g., Pearce and Bouton, 2001). Without supplementation, they only indirectly address the known importance of time and temporal variables in conditioning. An important exception, however, are the models of Wagner (e.g., 1981, 2003; Wagner and Brandon, 1989), which postulate time-linked processes initiated by CS and US presentations that can account for a number of temporal phenomena in classical conditioning (e.g., Todd and Bouton, 2012).

A different approach assumes that timing processes, rather than the incremental effects of trials, are the basis of conditioning and learning (e.g., Balsam et al., 2010; Balsam and Gallistel, 2009; Gallistel, 2012; Gallistel and Gibbon, 2000; Gibbon and Balsam, 1981). According to Gallistel and Gibbon (2000; see also Gibbon and Balsam, 1981), conditioned performance is determined by the animal's estimation of reinforcement rate, which depends fundamentally on its perception of time. On this view, the animal is sensitive to the amount of time that accumulates over separate CS presentations. During conditioning, conditioned responding emerges when the rate of reinforcement in the CS is judged to be higher than the rate of reinforcement in the background. During extinction, conditioned responding is assumed to stop once the contemporary reinforcement rate in the CS is judged to be lower than it was during conditioning. When developed in more detail, these ideas provide a testable time-based alternative to understanding conditioning and extinction. Because time is assumed

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http://dx.doi.org/10.1016/j.beproc.2013.08.006

to accumulate in the CS over trials, Bouton and Sunsay (2003) referred to this perspective as the "time-accumulation" view (see also Gottlieb, 2004, 2005).

First consider the time-accumulation conceptualization of conditioning. The Gallistel–Gibbon model assumes that the animal compares the rate of reinforcement in the CS and in the interval between trials (the intertrial interval or ITI), an estimate of the base rate of reinforcement. These rates are compared in a ratio of the CS rate over the background rate; when the value of the ratio exceeds a threshold, the animal responds to the CS. Because the rate of reinforcement is the reciprocal of the time between reinforcers, the trial on which the animal first decides to respond is proportional to the ratio of the time accumulated in the ITI (I) over the time accumulated in the CS (T; the so-called *I/T ratio*). More recent theoretical expositions (e.g., Balsam and Gallistel, 2009; Balsam et al., 2010) still propose this ratio at their core. Although the view immediately captures the fact that increasing the ITI increases the rate of conditioning and that increasing the CS duration decreases it, a number of experiments have produced results that are not consistent with it. For example, groups of subjects with identical I/T ratios have differed in their rates of conditioning depending on the specific values of I and T (Holland, 2000; Lattal, 1999) and in how T accumulating between reinforcers was actually distributed over separate trials (Bouton and Sunsay, 2003; Sunsay et al., 2004). Moreover, the magnitude of the US, and not merely its rate of occurrence, influences the point in conditioning at which the organism decides to respond (Morris and Bouton, 2006). Although trial-based theories emphasize a role for US magnitude in conditioning, the time-accumulation view ignores it. Several empirical analyses have thus created challenges for the time-accumulation account.

The present article is concerned, however, with time-based and trial-based accounts of extinction, the loss of responding that occurs when the CS is presented repeatedly without the US after conditioning (e.g., see Bouton, 2004; Bouton and Woods, 2008 for reviews). According to trial-based models, responding decreases in extinction because there is an incremental loss of associative strength or increase in inhibition as a consequence of each nonreinforced trial (presentation of the CS). In contrast, the Gallistel-Gibbon model proposes that animals stop responding in extinction when they determine that the rate of reinforcement in the CS is lower in extinction than it was during conditioning. The animal now compares the two rates in the form of another ratio. Because rate is again the reciprocal of time, the animal computes a ratio between the amount of time that has accumulated in the CS during extinction and the amount of time that previously accumulated in the CS between USs during conditioning. When the ratio exceeds a threshold, the animal stops responding. As before, time accumulating in the CS over trials, and not the effects of trials themselves, is what determines learning and performance.

The time-accumulation perspective makes especially interesting predictions about the partial reinforcement extinction effect, or PREE (see Mackintosh, 1974, for one review). In the PREE, the loss of responding that occurs in extinction is slower when conditioning has been conducted with a partial reinforcement schedule (in which nonreinforced trials have been intermixed with reinforced trials) than with a continuous reinforcement schedule (in which all trials are reinforced). According to the time-accumulation view, subjects that have undergone partial reinforcement have learned to expect the US after more accumulated time in the CS. As a consequence, it takes more accumulating time in the CS during extinction for the ratio of CS extinction time/expected time in the US to exceed the threshold. In contrast, more conventional views of the PREE emphasize a rather similar role of *trials*. For example, according to Capaldi's sequential view (e.g., Capaldi, 1967, 1994; see also Capaldi and Martins, 2010), the partially reinforced subject learns to expect the US after more nonreinforced trials ("N-length") than continuously reinforced subjects have. It therefore takes a longer string of nonreinforced trials to stop generalizing from conditioning to extinction (Capaldi, 1967, 1994). The two accounts both emphasize a generalization/discrimination process in explaining extinction and the PREE. But the time-accumulation view emphasizes what might be called the animal's *time expectancy* whereas the trial-based account emphasizes what might be called a *trial expectancy*.

The time-based account of the PREE was tested in a series of experiments using the rat appetitive magazine-entry preparation by Haselgrove et al. (2004). In each experiment, partially reinforced (PRF) and continuously reinforced (CRF) groups were compared in extinction after first giving them the same rate of reinforcement in the CS during conditioning. In Experiments 1 and 2, reinforcement rate was equated by giving CRF groups a single US on every trial and PRF groups no US on half the trials and two USs on the other half. In Experiments 3 and 4, CRF groups received CSs that were twice the duration of those received by the PRF groups (which were reinforced half the time). Despite the fact that both manipulations equated the groups on reinforcement rate in the CS (i.e., the amount of time in the CS between USs), a PREE was consistently observed. The results thus challenge the time-based view of the PREE, although they did not directly address how the PREE should be explained.

The present experiments continued to examine the time-accumulation and trial-based accounts of the PREE. In Experiment 1, we compared extinction in partially and continuously reinforced groups that received equivalent rates of reinforcement in the CS. The results, like those of Haselgrove et al. (2004), challenged the time-accumulation account. Experiment 2 then contrasted the time-accumulation and trial-based accounts more directly by testing whether extinction performance conformed to implications of either view. The results challenged an implication of the time-accumulation account, but confirmed an implication of the trial-based account. Overall, the results favor a trial-based as opposed to a time-based explanation of the partial reinforcement extinction effect.

2. Experiment 1

In the first experiment, rats received either PRF or CRF during acquisition using a method that equated the accumulated time in the CS between each US in the groups. In each conditioning session, PRF and CRF groups received exactly 160 s of accumulated time in the CS and eight trials in which a CS presentation was paired with a US. However, the PRF group received 16 10-s CS presentations in each session, only half of which were paired with the US. The CRF group received 8 20-s CS presentations in each session, all of which were paired with the US. The groups then underwent extinction. Half the animals in each group received extinction trials with a 10-s CS, and half received extinction with a 20-s CS. The design allowed us to compare the PRF and CRF conditions in extinction under identical conditions while controlling for any generalization decrement that might result from changing the CS duration between conditioning and extinction (cf. Haselgrove et al., 2004). Since all the rats received a US after 20 s of CS time during conditioning, the time-accumulation view predicts no PREE.

2.1. Method

2.1.1. Subjects

The subjects were 32 female Wistar rats from Charles River Laboratories (St. Constance, Quebec). They averaged 75–90 days old at the start of the experiment and were housed individually in suspended stainless steel cages in a room maintained on a 16:8-hr