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Short communication

Shifts in the psychophysical function in rats

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Abstract

The primary goal was to compare results from a free-operant procedure with pigeons [Machado, A., Guilhardi, P., 2000. Shifts in the psychometric function and their implications for models of timing. J. Exp. Anal. Behav. 74, 25–54, Experiment 2] with new results obtained with rats. The secondary goal was to compare the results of both experiments with dependent variables that were not used in the original publication. As in the original study with pigeons, rats were trained on a two-alternative free-operant psychophysical procedure in which left lever press responses were reinforced during the first and second quarters of a 60-s trial, and right lever press responses were reinforced during the third and fourth quarters of the trial. The quarters were reinforced according to four independent variable interval (VI) schedules of reinforcement. The VI duration was manipulated in each quarter, and shifts in the psychophysical functions that relate response rate with time since trial onset were measured. The results obtained with rats were consistent with those previously obtained with pigeons. In addition, results not originally reported were also consistent between rats and pigeons, and provided insights into the perception, memory, and decision processes in Scalar Expectancy Theory and Learning-to-Time Theory.

Keywords: Timing; Secondary data analysis; Psychophysical function; Temporal bisection; Rats; Pigeons

1. Introduction

The results of an experiment can be replicated either directly, where the conditions are the same as the original experiment, or systematically, where the conditions differ from those of the original experiment (Sidman, 1966). If successful, systematic replications increase the reliability of the original findings and their generality with respect to the factors that differed from the original experiment. The goals of the present article were to systematically replicate the results described by Machado and Guilhardi (2000) introducing differences in the species, independent variables, operant response, and experimental apparatus.

Machado and Guilhardi (2000) used a free-operant psychophysical procedure (FOPP) to test predictions from two theories of timing, Scalar Expectancy Theory (SET; Church, 1984; Gibbon, 1977; Gibbon and Church, 1990), and Learning-to-Time (LeT; Machado, 1997). The procedure is shown in Fig. 1. Pigeons were exposed to a 60-s trial signaled by a stimulus (e.g., houselight) that was divided into four 15-s segments, referred to as Segments 1, 2, 3, and 4. Left responses (e.g., keypecks) were reinforced during the first two 15-s segments (Segments 1 and 2) but not during the last two 15-s segments (Segments 3 and 4). Right responses were reinforced during the last two 15-s segments (Segments 3 and 4) but not during the first two 15-s segments (Segments 1 and 2). In each of the segments, reinforcers were scheduled according to one of two variable intervals, VI 40 s or VI 120 s.

The critical manipulation was whether the VI schedules during Segments 2 and 3 were equal (40–120|120–40 or 120–40|40–120, for Segments 1, 2, 3, and 4, respectively) or different (40–120|40–120 or 120–40|120–40). The overall reinforcement rate for each of the responses (left during Segments 1 and 2, and right during Segments 3 and 4) was kept constant. The pigeons were divided into two groups. Group EQU was exposed to equal VIs during Segments 2 and 3; that is, 120–40|40–120 in one condition, and 40–120|120–40 in another condition. Group DIF was exposed to different VIs during Segments 2 and 3; that is, 120–40|120–40 in one condition, and 40–120|40–120 in another condition. The groups were trained on the two conditions in separate blocks of sessions.

Two psychophysical functions relating the proportion of right responses to time since trial onset were obtained, one function per condition. Next, the magnitude of the (horizontal) shift between the two functions was calculated. The purpose of the original experiment (Machado and Guilhardi, 2000) was to determine whether the psychophysical function would shift

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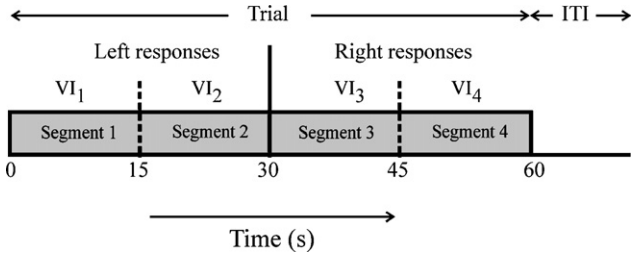

Fig. 1. Machado and Guilhardi (2000) free-operant psychophysical procedure.

when the reinforcement rates around the middle of the trial were the same (Group EQU) or different (Group DIF). More specifically, the purpose was to determine whether the magnitude of the shift would be greater for Group DIF than for Group EQU. The results showed a greater shift in the psychophysical function for Group DIF than for Group EQU.

Machado and Guilhardi's (2000) results extended the results described by Bizo and White (1995). These authors manipulated the overall reinforcement rate associated with the two responses. In one condition, they associated a VI 45-s schedule with the left response and a VI 90-s schedule with the right response (condition 45|90). In a second condition, the VI schedules were reversed (condition 90|45). In both conditions, left keypecks were reinforced during the first but not the last 25 s of a trial, whereas right keypecks were reinforced during the last but not the first 25 s of a trial. The pigeons switched from the left to the right key later during condition 45|90, and earlier during condition 90|45, producing a shift in the psychophysical functions between the two conditions. Similar results were observed in another experiment with the conditions 40|120 and 120|40. Machado and Guilhardi's (2000) results extended Bizo and White's (1995) results by showing that, in addition to differences in the overall reinforcement rate, differences in the reinforcement rate around the middle of the trial (i.e., at the time of switching from the first to the second response) determine the shifts in the psychophysical function.

Similar results were also obtained by Stubbs (1980, Experiment 3). In that experiment, pigeons were trained on a 15-s trial during which left responses were reinforced during the first but not the last half of the trial, and right responses were reinforced during the last but not the first half of the trial. Although the overall reinforcement rate was kept constant for the left and right responses, in some conditions the local reinforcement rate during the last half of the trial was manipulated. Local changes in the reinforcement rate around the middle of the trial produced shifts in the psychophysical function. Machado and Guilhardi's (2000) results replicated Stubbs' (1980) results even though there were major procedural differences between the two experiments. For example, Stubbs used a changeover response key such that the pigeons could only switch between responses once per trial. In addition, in Stubbs' procedure, a trial terminated whenever reinforcement occurred, which exposed the pigeons to the early part of the trial more often than the later part of the trial. Nonetheless, the results were remarkably similar showing that differences in the local reinforcement rate around the middle of the trial are sufficient to produce shifts in the psychophysical function, even when the overall reinforcement rates associated with the two responses remain equal.

The present article aimed to replicate the Machado and Guilhardi's (2000) results while introducing differences in the species (rats instead of pigeons), variable interval durations (VI 30 s instead of 40 s), operant response (lever press instead of keypeck), and apparatus. If successful, this systematic replication would increase our confidence in the claim that the shifts are caused by the manipulation of the reinforcement rate around the time of switching, which was preserved between replications, and not by other factors, which were not preserved between replications. Although Machado and Guilhardi (2000) has been cited 13 times (Science Citation Index search, August 18, 2006), it has not been replicated, or extended to other species. Most of these articles referred to the procedure and results obtained by Bizo and White (1995) and, although these experiments used different species, variable interval durations, response, and apparatus, they provided no further evidence to support the specific conclusion that reinforcement rate around the time of switching between the first and second responses, and not differences in overall reinforcement rate per se, determine shifts in the psychophysical function (e.g., Body et al., 2006; da Silva and Lattal, 2006). The remaining citations referred to the theoretical conclusions drawn by Machado and Guilhardi (2000) and, like the other articles, did not replicate the results described (e.g., Bizo et al., 2006; Machado and Pata, 2005; Whitaker et al., 2003).

Since the original data from Machado and Guilhardi's experiments were also available, secondary data analysis of the raw data (Church, 2002) could be based on new dependent variables. One such variable is the psychophysical function based on individual trials. The form of a psychophysical function for a single trial may consist of an abrupt change from one response to another, which can be characterized as a step function. Preliminary analysis showed that most of the single-trial response rate functions were step-like; that is, one function (responses reinforced in the first half of the trial) went down abruptly at time t_1, and another function (responses reinforced in the second half of the trial) went up at time t_2. Therefore, a transition point (tp) may be defined for each trial by the midpoint between t_1 and t_2. This alternative, single-trial analysis is richer than analyses based on the mean psychophysical functions because it yields the entire distribution of the t_1, t_2, and transition points (not just their means). The familiar ogival psychophysical function may result from averaging such single-trial step functions (Church et al., 1994; Schneider, 1969). Hence, the question is whether or not the conclusions of Machado and Guilhardi (2000) hold with this new trial-based analysis. More specifically, will the mean transition points given by the psychophysical functions fitted to the averaged data match the mean transition points given by single-trial analysis? Will the two types of analysis yield shifts in the same direction and of similar magnitude? The new analysis will also reveal additional patterns in the data such as the potential correlations between t_1 and t_2. The purpose of using this alternative measure of the shift, like the purpose of using different species, was to extend the generality of the conclusions of the original study. Such analyses have been reported for the fixed-interval (Schneider, 1969) and peak procedures (Church