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Short communication

Differences between simultaneous and blocked training detected by a transfer test

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Abstract

Secondary data analysis was used to compare responding early on a transfer test from rats previously trained simultaneously or successively on multiple temporal discriminations for the same number of trials [Guilhardi, P., Church, R.M., 2005a. Dynamics of temporal discrimination. Learn. Behav., 33, 399–416]. Three fixed intervals (30, 60, and 120 s) were signaled by three stimuli (light, noise, and clicker). Twelve rats were trained with the three stimulus-interval pairs intermixed on each experimental session (simultaneous condition); 12 other rats were trained in successive blocks of 10 sessions on each pair (blocked condition). Then, all rats had a transfer test in which all three stimulus-interval pairs were presented intermixed on each session. Rats in the simultaneous and blocked condition responded similarly during training, but differently during early stages of the transfer test. One possibility is that rats in the blocked condition were controlled by the previous interval, not by the current stimulus. These results challenge the usual assumptions from models of timing and conditioning that both simultaneous and blocked training produce learning of the associations between stimulus and interval in a multiple interval training task.

Keywords: Memorization; Relearning; Fixed interval; Rat; Secondary data analysis; Learning; Performance; Generalization decrement

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1. Introduction

Rats can be trained to respond differentially to fixed intervals signaled by different stimuli. The problem was to determine whether or not, with the same amount of training, there are differences in learning and performance when the multiple intervals are trained in a blocked or simultaneous condition.

In a study designed to describe and explain the acquisition of multiple temporal discriminations associated with different cues, Guilhardi and Church (2005a) trained rats on three discriminative fixed-interval (FI) schedules of reinforcement under two conditions: In a blocked condition, a particular stimulus-interval pair (e.g., noise-30 s) was trained on sessions 1–10, a second stimulus-interval pair (e.g., light-60 s) was trained on sessions 11–20, and a third stimulus-interval pair (e.g., clicker-120 s) was trained on sessions 21–30; in a simultaneous condition, the three stimulus-interval pairs were presented intermixed on each of the 30 sessions of training.

Under the blocked and simultaneous conditions the rats responded differentially to the three stimulus-interval pairs. In both conditions, the discrimination appeared in measures sensitive to the stimulus (such as the stimulus discrimination ratio, i.e., the response rate during a stimulus relative to the response rate prior to the stimulus) and in measures sensitive to the interval (such as the temporal discrimination ratio, i.e., the response rate at the end of an interval relative to the response rate at the beginning of the interval). The fact that at asymptote rats trained on the blocked and simultaneous conditions responded differentially to the three stimulus-interval pairs, suggests that performance was not affected by training conditions. The question remains, however, whether or not there were differences in learning between the two conditions.

There is an important distinction between performance as a dependent variable, and learning as an intervening variable. A similarity in performance under different treatments is not necessarily due to a similarity in learning. As Rescorla (1988) has emphasized, “The assessment of the impact of an independent variable on learning can only be made when a common test

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procedure is employed" (pp. 335). This assessment is called a transfer test.

After the initial training, the rats in the simultaneous and blocked conditions were transferred to a common condition (a transfer test) in which all three intervals were presented in the same session (i.e., the simultaneous condition). Although an analysis of the averaged data from 20 or more cycles on these sessions did not identify differences between the original training conditions (Guilhardi and Church, 2005a), the first cycles of the transfer test might have revealed a difference between the two conditions. Because the primary data used by Guilhardi and Church (2005a) were readily available on the Psychonomic Society website (http:///www.psychonomic.org/archive/) and on our Brown University website (http://www.brown.edu/Research/Timelab), we were able to test that possibility.

2. Materials and methods

A secondary data analysis of Guilhardi and Church's (2005a) original data was performed in the present study. A brief summary of the methods used is described below. For a complete description of the methods, including housing and apparatus description, and additional procedures, see the original published study.

2.1. Animals

Twenty-four male Sprague–Dawley rats were used. They were fed with 45 mg Noyes pellets (Improved Formula A) in the experimental sessions, and 15 g of FormuLab 5008 food in the home cage after the experimental sessions.

2.2. Apparatus

Twelve standard operant chambers were used. Each chamber was equipped with a food cup, a water bottle, a food pellet dispenser, LED-photocells that record head entries into the food cup and modules that generate three stimuli, referred to as "noise," "light," and "clicker."

2.3. Procedure

The experimental sessions consisted of 60 cycles or 150 min, whichever came first. Each cycle consisted of a 20 s period with no stimulus, followed by a period with a stimulus on. Immediately after a fixed interval, the first head entry into the food cup, measured by the breaking of a photo beam in the food cup, delivered the food, terminated the discriminative stimulus, and started the next cycle. If the rat had its head in the food cup after the fixed interval elapsed, a new head entry was required for food to be delivered.

During baseline, all animals were trained for 30 sessions under 30, 60, and 120 s fixed-interval schedules of reinforcement differentially signaled by noise, light, or clicker. Twelve rats were randomly assigned to the blocked condition, and the other 12 rats were assigned to the simultaneous condition. Training of the blocked condition consisted of 10 sessions with one stimulus-interval pair, then 10 sessions with a second stimulus-interval pair, and then 10 sessions with the third stimulus-interval pair. The order of training of the fixed intervals was counterbalanced across rats. Training for the simultaneous condition consisted of 30 sessions in which one of the three possible stimulus-interval pairs (e.g., light-30 s, noise-60 s, and clicker-120 s) was presented randomly with equal probability on each cycle of each session. After 30 sessions of training, rats from both conditions had received approximately 600 cycles of training on each stimulus-interval pair.

During a second phase, referred to as transfer test sessions, there were 36 sessions in which rats were presented with the two extreme cued intervals 30 and 120 s (with stimulus-interval pairings consistent with baseline training) and one of nine intervals between 30 and 120 s distributed in an approximately logarithmic way paired with the stimulus used for the 60 s interval during baseline training. The three stimulus-interval pairs were presented randomly across cycles within each transfer test session.

2.4. Data analysis

The secondary data analysis reported in this study was performed on the data set downloaded from the Psychonomic Society Publications web site on March 30, 2006 (Guilhardi and Church, 2005b). Mean responses per minute as a function of time since stimulus onset (referred to as "temporal gradients") during baseline training and transfer test are shown. For statistical comparisons, each temporal gradient was fitted individually with the best linear function (least squares criterion) for the first 30 s following stimulus onset, and the slopes of these linear functions were compared. The means and standard deviations of the slopes obtained for each rat and for each gradient are reported.

3. Results

The results for baseline training and transfer test for both the simultaneous and blocked conditions are described below.

3.1. Baseline training

Asymptotic performance on baseline training of simultaneous and blocked conditions was similar. The top panels of Fig. 1 show the temporal gradients for the 30, 60, and 120 s fixed intervals averaged across rats and across the last half of the baseline training sessions. For the simultaneous condition, this consisted of all cycles of sessions 16–30 (top left panel) and for the blocked condition this consisted of all cycles of the last five sessions of each of the three 10-session blocks, sessions 6–10, 16–20, and 26–30, (top right panel). For the simultaneous condition, the mean and standard deviation (in parenthesis) of the slopes of the linear fits for the first 30 s of each gradient were 4.80 (1.12), 0.89 (0.66), and 0.10 (0.08) for the 30, 60, and 120 s gradients, respectively; and for the blocked condition they were 4.55 (0.89), 0.51 (0.28), and 0.06 (0.08) for the 30, 60, and 120 s gradients, respectively. The slopes of the gradients were related to the duration of the fixed intervals in both conditions ($F_{2,44} = 418$, $p < .001$), no

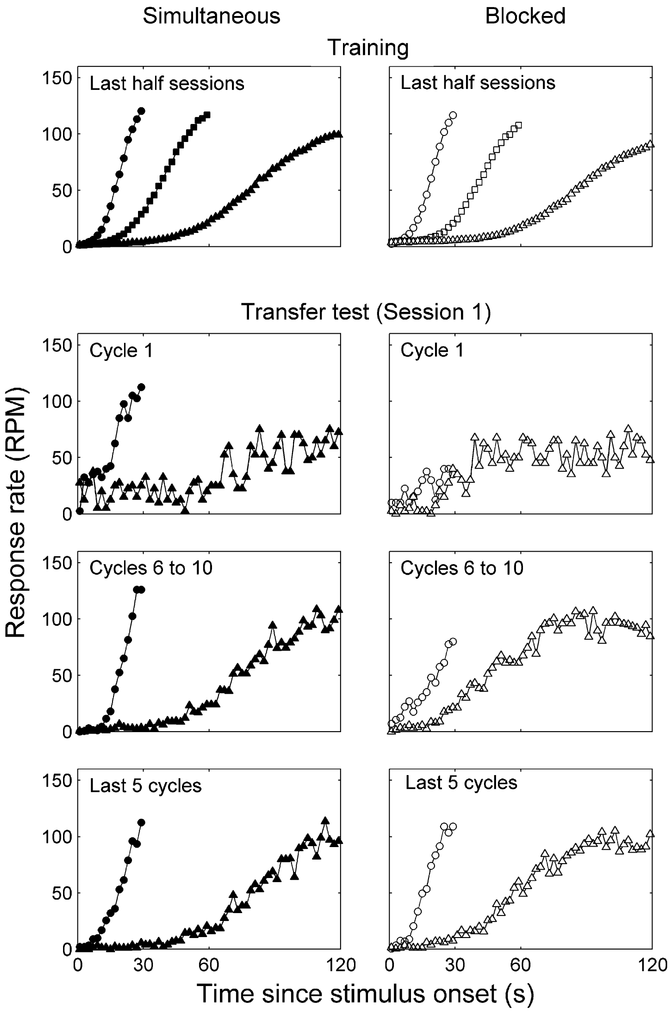

Fig. 1. Response rate during the FI-30, 60 and 120 s (circles, squares and triangles, respectively) as a function of time since stimulus onset for the simultaneous (left column) and blocked (right column) conditions. Top row shows data for the last half of the sessions of baseline training, and bottom three rows show data for different cycles of the first transfer test session.

effect of condition was observed ($F_{1,22} = 1.59$, $p = .221$), and the interaction between intervals and conditions was not statistically significant ($F_{2,44} = .493$, $p = .614$).

3.2. Transfer test

Performance of the simultaneous and blocked conditions differed on the first session of the transfer test. The temporal gradients of the simultaneous condition were a function of the fixed intervals on all cycles, including the first one. In contrast, the temporal gradients of the blocked condition initially were not a function of the fixed intervals, but gradually became a function of the intervals in a cycle-by-cycle basis.

The bottom six panels of Fig. 1 show the temporal gradients for the 30 s (circles) and 120 s (triangles) fixed intervals on cycles 1 (second row), 6–10 (third row) and last five cycles (fourth row) of the first session of transfer test for the simultaneous condition (left panels, filled symbols) and for the blocked condition (right panels, open symbols). The first 30 s of each gradient was fitted with the best linear function, and the individual slopes were compared. Analysis of variance on the slopes for the first cycle with interval (30 and 120 s) as the within-subject factor and condition (simultaneous and blocked) as the between-subject factor showed an effect of interval ($F_{1,22} = 8.49$, $p = .008$), no effect of condition ($F_{1,22} = 2.33$, $p = .141$), and a significant interval-condition interaction ($F_{1,22} = 7.47$, $p = .012$).

In the simultaneous condition, the slopes of the fits for the 30 and 120 s gradients were a function of the fixed intervals starting from cycle 1 ($t_{11} = 3.78$, $p = .003$). The mean and standard deviation (in parenthesis) of the slopes were 3.72 (3.05) and −0.02 (1.43) for the 30 and 120 s gradients, respectively. In the blocked condition, however, the slopes of the linear fits were not a function of the fixed intervals on the first cycle of the first session of the transfer test ($t_{11} = .14$, $p = .894$). The mean and standard deviation (in parenthesis) of the slopes of the linear fits were 1.04 (1.65) and 0.92 (2.09) for the 30 and 120 s gradients, respectively.

In the blocked condition, there was a gradual adjustment in both gradients as a function of cycles within the first session of transfer test. The gradients were similar in the first cycle of transfer test in session 1 (second row, right panel of Fig. 1), and differed in later cycles (bottom right panel of Fig. 1). The slopes of the fitted functions were compared for the last five cycles and an analysis of variance with interval (30 and 120 s) as the within-subject factor and condition (simultaneous and blocked) as the between-subject factor showed a significant effect of interval ($F_{1,22} = 124.04$, $p < .001$), no effect of condition ($F_{1,22} = .75$, $p = .397$), and no interval-condition interaction ($F_{1,22} = .13$, $p = .721$). The mean and standard deviation (in parenthesis) of the slopes were 4.11 (1.57) and 0.10 (0.23) for the 30 and 120 s gradients of the simultaneous condition, respectively; and 4.57 (1.98) and 0.28 (0.39) for the 30 and 120 s gradients of the blocked condition, respectively.

Fig. 2 shows performance of the blocked condition on sessions 1, 2, and 10 of the transfer test. The three panels in the first column (session 1) were reproduced from Fig. 1 for comparison. On the first cycle of session 2 the slopes of the linear fits of the gradients were already a function of the fixed intervals ($t_{11} = 2.52$, $p = .028$). The mean and standard deviation (in parenthesis) of the slopes were 2.22 (2.79) and 0.33 (0.60) for the 30 and 120 s gradients, respectively. This was also observed on the first cycle of session 10 ($t_{11} = 3.03$, $p = .011$), in which the mean and standard deviation (in parenthesis) of the slopes were 2.60 (2.67) and 0.17 (0.25) for the 30 and 120 s gradients, respectively.

4. Discussion

Rats achieved similar steady state performance on three fixed-interval schedules of reinforcement when trained simultaneously on the three intervals in each session (simultaneous condition), or when they were trained in blocks of 10 sessions on each of the intervals successively (blocked condition). On the first cycles of the transfer test, however, the performance of the rats trained on the simultaneous and blocked conditions were different. Rats trained on the simultaneous condition continued to

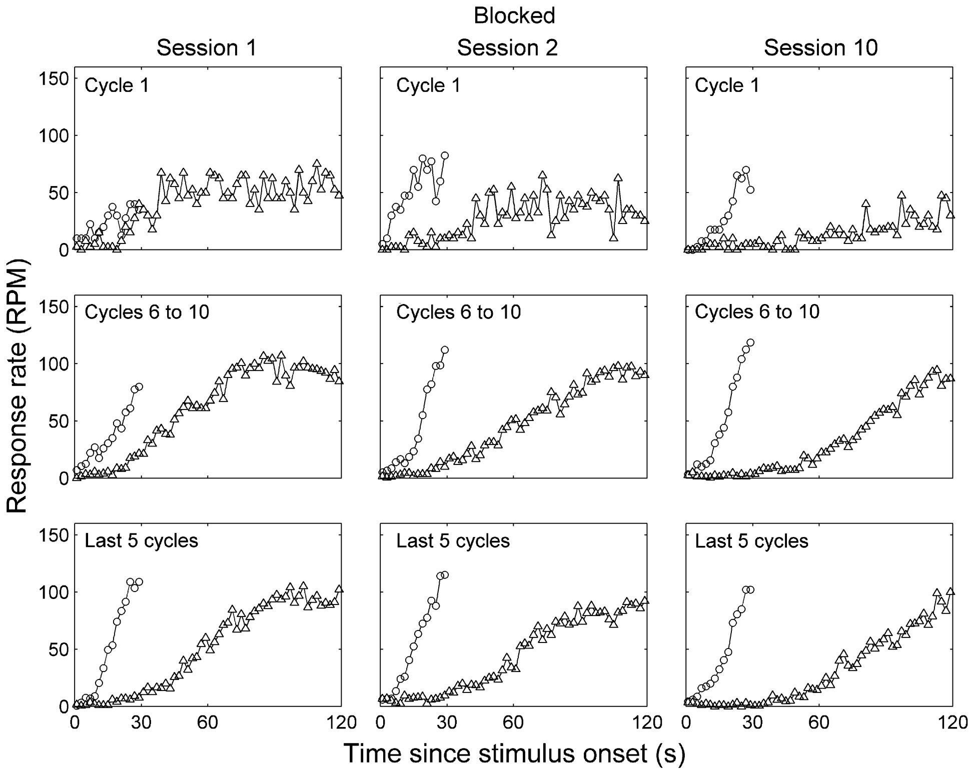

Fig. 2. Response rate during the FI-30 and 120 s (circles and triangles, respectively) as a function of time since stimulus onset for the blocked condition on different cycles (rows) of different sessions (columns) of the transfer test.

respond differentially to the different time intervals associated with the different stimuli. In contrast, rats trained on the blocked condition did not respond differentially to the stimuli early in the transfer test. These results suggest that the learning of the multiple fixed intervals may have been enhanced by training them simultaneously rather than successively.

The usual assumptions are that, in a discriminative fixed-interval schedule of reinforcement, an animal learns a stimulus discrimination (such as light is associated with food), a temporal discrimination (such that a particular interval is associated with food), and the association of a stimulus and temporal discrimination (such as a light after a particular interval is associated with food). Theories of conditioning such as the Rescorla–Wagner model (Miller et al., 1995; Rescorla and Wagner, 1972), emphasize the stimulus discrimination; and theories of timing, such as scalar timing theory (Gibbon, 1977; Gibbon et al., 1984), emphasize the temporal discrimination. To account for both stimulus and temporal discrimination, conditioning theories have been extended to account for temporal factors (e.g., Sutton–Barto Model, Sutton and Barto, 1981); timing theories have been extended to account for conditioning factors (e.g., Rate Estimation Theory, Gallistel and Gibbon, 2000), and integrated theories of stimulus and temporal factors have been developed (e.g., Learning to Time, Machado, 1997; and Packet Theory of Timing and Conditioning, Kirkpatrick, 2002; Kirkpatrick and Church, 2003). In most of the theories designed to account for both stimulus and temporal discriminations, the animal learns to respond more (a) in the presence than the absence of the stimuli, (b) near the times, rather than far from the times, at which the reinforcers occur, and also (c) at different times for the different stimuli. Most theories do not make different predictions for the simultaneous and blocked conditions; some provide a basis for interference effects in the simultaneous condition. Further theoretical development will be necessary for a quantitative theory of conditioning and timing to account for behavioral differences between these two training procedures, especially the facilitating effects in the simultaneous condition.

At asymptote during training, both the rats in the simultaneous and blocked conditions had different temporal gradients of responding for each of the stimuli. One of the ways they could have done so is to have learned the association of each interval with each stimulus. This will be referred to as “memorization.”

Because the three different stimulus-interval pairs were presented intermixed within each session, rats in the simultaneous condition must have memorized during training, i.e., learned the association of each interval with each stimulus. Although it is plausible to assume that rats in the blocked condition also memorized during training, they could have performed the task at asymptote equally well with a temporal discrimination based on the previous temporal interval alone. Rats in the blocked condition could have adjusted their performance to the new interval on each transition during training (sessions 11 and 21) by relying on the interval previously reinforced. Such adjustment may not imply the rats learned the association between the stimulus and interval. This use of the previous interval regardless of the stimulus presented will be referred to as “relearning.”

A direct comparison of the performance of the rats during the simultaneous and blocked training does not distinguish between learning and performance, and therefore does not invalidate the hypothesis that the rats in the blocked condition did not learn the associations between stimuli and intervals. In order to isolate learning effects, a transfer test is often used. In the present experiment, the original training conditions of the two groups of animals were different (e.g., simultaneous and blocked), but the conditions of transfer test were the same.

If both groups of rats memorized the stimulus-interval pairs and performance was controlled by the stimulus, then differential responding to the different stimuli should be observed regardless of training conditions. On the other hand, if rats in the blocked condition rapidly relearned any new intervals, no differential performance to the stimuli should be observed early in a transfer test. Results showed that rats in the simultaneous condition responded differentially to the different stimuli, but rats in the blocked condition did not. This suggests that rats in the blocked condition relearned changes in the interval, and rats in the simultaneous condition memorized the stimulus-interval associations.

Results of the present study also suggest that the rats relearned when relearning was possible, but memorized when it was not. When the previous cycle was a reliable predictor of time of reinforcement in the current cycle for the blocked condition (baseline training), the rats relearned; when the previous cycle became an unreliable predictor of time of reinforcement for the blocked condition (transfer test phase), the rats memorized the association between stimuli and intervals in only one session, as demonstrated by the differential responding to each stimulus observed in the first cycle of the second session of transfer test (middle-top panel of Fig. 2).

The conclusions about memorization and relearning obtained in the present study are based on the transfer design in which a common testing procedure is used after different training procedures. In such experiments, procedural changes between the training and the transfer test conditions can affect performance (generalization decrement). Although the individual cycles during transfer test were similar to those used during baseline training for all rats (with the exception of the intermediate intervals during transfer test paired with the stimulus previously trained with the 60 s interval during baseline training), it is possible that the new sequence of presentations of cycles (intermixed within a session) disrupted performance of the rats in the blocked condition.

Regardless of the factors responsible for the observed differences in behavior of the rats in the simultaneous and blocked conditions, the present secondary data analysis described counterintuitive results that current models of timing and conditioning need to explain. Further experiments need to be designed to determine whether the effects observed are due to relearning or generalization decrement. Caetano (2006) described a procedure in which changes in the interval trained for the blocked condition occurred multiple times and allowed the investigator to observe performance of rats during the multiple transitions between blocks. The blocked training consisted of blocks of one session (60 cycles), instead of 10 sessions, with one of the three different stimulus-interval pairs trained daily for approximately 100 sessions (same stimuli and intervals used in the present study). The first cycle of each of the training sessions can be viewed as a transfer test, which indicates whether the rats have memorized or relearned the intervals. Results showed that performances on the first cycle of each of the training sessions were not differential, suggesting that the rats did not memorize the intervals. The fact that the rats had a great amount of experience in the transfer test (one of the three intervals every session, for approximately 100 sessions) suggests that perhaps the animals relearned the new intervals daily, and performance was not an effect of a generalization decrement.

Other experiments that manipulate the continuum between simultaneous and blocking conditions (e.g., manipulations of the probability of presenting the same or a different interval on every cycle within a session) could provide more conclusive evidence about the determining factors of the difference in performance observed between the two conditions, which could be incorporated in current models of timing and conditioning.

The present study illustrates the potential value of accessible data archives, and it encourages secondary data analysis. The present article addresses a question that had not been considered in the original article (Guilhardi and Church, 2005a). If only the information from published tables, figures, and statistical tests were available, this problem could not have been addressed without repeating the experiment. Because the primary data (the precise times of all stimuli, responses, and reinforcements) were archived, it was feasible to do secondary data analysis. This study, and others (e.g., Crystal, 2004) are examples of researchers in animal cognition using secondary data analysis to describe new results from data previously collected and published.

Of course, collection and analysis of primary data remains essential for answering questions that require a particular experimental design or dependent variable that is not available. In some cases, the appropriate experiment has not been done, or an experiment is sufficiently important that it should be replicated; in other cases the experiment has been conducted but the primary data are no longer available.

A workshop sponsored by the National Institute of Mental Health, "Data Archiving for Animal Cognition Research," dealt with the role of data archiving in research, the content of data archives, technical and archival standards, and organizational, financing, and policy issues. It also contained recommendations, some of which are being implemented (Kurtzman et al., 2002).

In summary, findings of the present study suggest that (1) learning of multiple fixed intervals may be enhanced by training them simultaneously rather than successively; (2) perhaps the rats memorize in the simultaneous condition but relearn in the successive condition; (3) current models of timing and conditioning need to be modified to account for the results observed; and finally, (4) this study encourages the sharing of data bases and the use of secondary data analysis.

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