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The effect of stimulus discriminability on strategies for learning multiple temporal discriminations

Paulo Guilhardi[a,b,*], Marina Menez[a,c], Marcelo S. Caetano[a,d,e], Russell M. Church[a]

[a] Brown University, United States
[b] New England Center for Children, United States
[c] Universidad Nacional Autónoma de México, Mexico
[d] The John B. Pierce Laboratory, United States
[e] Yale University School of Medicine, United States

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ABSTRACT

The goal was to identify training conditions under which temporal intervals that are signaled by different stimuli are memorized (i.e., the temporal behavior is readily shown to be under stimulus control). Undergraduate students were trained on three signaled temporal discriminations using a peak procedure. The intervals were trained in either blocks of trials or with trials intermixed within the session, and then they were given a transfer test with intermixed trials. There were two levels of stimulus discriminability, defined by the similarity of the stimuli. Most participants memorized the intervals when the discriminations were intermixed within the session, or were easy, but not when the discriminations occurred in blocks and were difficult. In the transfer tests, those participants trained in the difficult discrimination that occurred in blocks of trials typically continued to perform as they did during the last-trained interval, regardless of the stimulus presented. These results are better explained by a memory retrieval than a memory storage account.

The present experiment attempted to determine whether the order of presentation and the discrimination difficulty of signaled temporal discriminations affect *learning* (i.e., memory content), without affecting *performance*. More specifically, the present experiment describes effects of (1) the order of trials (trials that were intermixed within a session compared to trials that were presented in blocks), and (2) stimulus discrimination difficulty (discriminations that were hard compared to discriminations that were easy), on training multiple signaled temporal discriminations.

Rescorla (1988) made a clear distinction between learning as an intervening variable, and performance as a dependent variable by showing that similarity in performance under different treatments does not imply similarity in learning. Moreover, Rescorla showed that well-designed transfer tests (procedural changes from the original training conditions) can be successful in assessing both performance, and what has been learned. The distinction between learning and performance is similar to the distinction between intervening variables and output in a process theory of learning: the input is the procedure, the intervening processes include perception, memory, and decision, and the output consists of times of responses.

With signaled fixed-interval discriminations of rats, Caetano et al. (2007) found that training procedures that produced very similar performance could be shown by a transfer test to be based on different learning mechanisms. Groups of rats had the same amount of training on three signaled temporal discriminations that differed only on the sequence in which the three cued intervals were trained. For some rats, the three intervals were presented intermixed within each experimental session, while for other rats, the three intervals were trained successively in three blocks of multiple sessions (i.e., 10 sessions).

Although performance at the end of training was very similar across the two groups, a transfer test indicated that very distinct learning occurred. Rats trained on the three temporal discriminations with trials intermixed within the session showed that stimuli controlled performance on the three intervals, which was referred as *memorization*; rats trained in successive blocks (i.e., successive blocks of multiple sessions training only one interval throughout the block, but changing across blocks) showed that the performance was not controlled by the stimuli but that it rapidly adjusted to the interval being trained, which was referred to as *relearning*. In another experiment (Caetano, 2006), it was shown that the differential learning across intermixed and blocked training groups of rats that had the same overall amount of training was preserved,

* Corresponding author at: Department of Psychology, Box 1853, Brown University, Providence, RI 02912, United States. Tel.: +1 401 863 3979; fax: +1 401 863 1300.
E-mail address: Paulo_Guilhardi@Brown.edu (P. Guilhardi).

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even if the size of the block was reduced to a single session (i.e., one interval trained throughout an entire session) and the number of reversals between sessions was greatly increased (i.e., from 1 to 35).

For the study of the conditions affecting memorization of human participants, a psychophysical procedure was developed that produced the standard scalar timing results, but was less boring for participants (Guilhardi et al., Submitted for publication). It was a modified version of the peak procedures originally developed for nonhuman animals (Bitterman, 1964; Catania, 1970; Roberts, 1981). It consisted of a bull's eye target that moved at a constant velocity from left to right on the middle of the computer screen. Keyboard presses produced shots at a fixed location (center of the screen) and they were signaled by a flashing yellow circle. Points were delivered for target hits and removed for target misses. Stimuli were determined by the background color of the screen, and intervals were determined by the velocity of the target. The target reached the center of the screen at 2, 2.83, or 4 s (short, intermediate, or long intervals, respectively). In some trials, a white horizontal rectangle covered the target trajectory but the background stimulus remained visible anywhere else in the screen. During these trials, the position of the target on the screen could not be used as a cue, and in order to successfully obtain points, participants had to base their responses on time since the initial movement of the target. Using this signaled fixed-interval discriminations of human participants, it was found that response rate as a function of time approximated a normal function with peak at around the time at which the target hit the middle of the screen. Consistent with the results obtained with rats (Caetano, 2006; Caetano et al., 2007), humans memorized the signaled interval durations when the intervals were trained intermixed within a session, and failed to memorize when the participants were trained on the three intervals on 3 different days. In addition to the previously obtained results with rats, memorization occurred in the transfer test when the participants were trained on the three intervals in blocks of trials in the same day (within-session blocks). Whether a short interval between training blocks of trials is a necessary condition for memorization to occur or not, remains to be determined.

A standard procedure for training multiple temporal discriminations is to signal different intervals with different stimuli. This normally leads to differential responding to the stimuli, which is referred as, "stimulus control". In both the intermixed and blocked conditions, the participants had the same number of stimulus-interval pairs, just in different orders. In the intermixed conditions, they learned the relationship between the stimulus and interval; but in the blocked condition they did not learn the relationship between the stimulus and the interval.

The present experiment provides another example in which distinct training procedures produce very similar performance, but transfer tests detected substantial differences in learning. It used the same human procedure described above with the addition of a discrimination difficulty factor (measured by the similarity of the stimuli) in order to determine whether or not, with the same amount of training, there are differences in human learning and performance on multiple temporal discriminations that are signaled by different stimuli when these temporal discriminations are trained intermixed within a session, or in blocks of many trials within a session. As described above, training of multiple temporal discriminations either intermixed or in blocks within a session (but not across sessions) produced memorization when the discrimination was relatively easy (different screen background colors). The question addressed by the present experiment was whether or not the same results would be obtained if the discrimination were made substantially more difficult.

1. Method

1.1. Participants

Twenty-four undergraduate students from the Psychology Department at Brown University participated in the experiment. The protocol was approved by the Institutional Review Board (IRB) from Brown University and all participants voluntarily provided written informed consent.

1.2. Equipment and materials

The experiment was conducted in a small room isolated from external noise. Participants sat in front of a PC with a color monitor. Responses were made on a Dell SK-8115 USB keyboard. The computer monitor was a 15-in. Gateway VX700 CRT set to 1024×768 pixels resolution and 85 Hz refresh rate. Auditory stimuli were presented through a pair of Sony MDR-V500 Dynamic stereo headphones. The computer was equipped with a 2.13 GHz Intel Core Duo processor, 2 GB of RAM memory, and a NVidia GEForce 8600 GTS video card.

The experimental procedures were programmed using Matlab and a toolbox (Psychophysical Toolbox, www.psychtoolbox.org; Brainard, 1997; Pelli, 1997) that was developed to record the occurrence of experimental events with a 1-ms resolution. The visual stimuli were presented within 13-ms of the programmed time due to the refresh rate of the computer monitor, and the discrepancy between the programmed and presented visual stimulus (recorded with 1-ms precision) may be taken into account in the selection of intervals to minimize error and, for increased accuracy of reported durations, during data analysis.

1.3. Procedure

The twenty-four participants were trained for one session on a multiple cued-interval task that lasted approximately 45 min. They were asked to sit in front of the computer monitor and were presented with a target on the computer screen that consisted of four concentric circles, colored red, white, red, and white, with a black central circle (bull's eye) as shown in the top of Fig. 1 (left panel). The overall radius of the target was 60 pixels, with the radius of each of the inner circles 12 pixels smaller than the previous one.

The participants initiated each trial by pressing the space bar of the keyboard. This produced an auditory "click," and the target moved horizontally at a constant speed from left to right across the middle of the computer screen. The time for the target to reach halfway across the monitor was 2, 2.82 (the geometric mean of the 2- and 4-s intervals), or 4 s after the click, depending on the color of the background screen (light green, regular green, and dark green, respectively). (See the panel labeled "Regular Trial" on the top of Fig. 1.) The 2-, 2.82-, and 4-s intervals are referred to as "short", "intermediate", and "long" intervals.

All shots were aimed at the center of the screen, and they occurred when the participants pressed the "control" key located on the right side of the computer keyboard. Each shot was signaled by an auditory stimulus (a gun-shot sound) and, on regular trials, a 0.1-s visual stimulus (5 pixels radius yellow dot) appeared in the center of the screen (on or off the target, depending on the target position on the screen at the time of the shot). Thus, the participant could miss the target by responding either too early or too late, and would hit the target by responding at the time it was passing through the center of the monitor. At the end of each trial, the participant was provided with feedback (5 points for each shot in the central circle; 1 point for all other shots on target; and −1 point for all shots that missed the target). These points were displayed in a table on the top left corner of the screen with the sum of points