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Determinants of Temporal or Stimulus Control in Humans and Rats

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Humans and rats can discriminate different fixed intervals (FIs) that are signaled by different stimuli. With only a few pairings of stimuli with intervals, temporal performance becomes a function of the stimuli, with responding increasing earlier for stimuli that signal shorter FIs compared to stimuli that signal longer FIs. As predicted by timing and conditioning models, the amount of training with the different stimuli and intervals determines the development of such stimulus control. This study reviews some earlier work from our group suggesting that the amount of training is necessary, but not sufficient, to account for the development of stimulus-controlled performance. Moreover, it describes an experiment in which participants were trained in a computerized shooting task with three FIs (target speeds) signaled by three stimuli (different background colors). In the first phase, the number of trials trained with each FI was held constant (60 trials each) across five experimental groups, but the order in which these trials were trained differed between groups, from a randomly determined FI in each trial (intermixed) to three consecutive blocks of 60 trials each (blocked). Intermediate groups had blocks of 10, 20, and 30 consecutive trials of each FI. Results showed that, although the amount of training was held constant across groups, the longer the training block the fewer the participants who demonstrated stimulus-controlled performance. In Phase 2, another 60 trials of each FI were trained, but intermixed for all groups. Results showed stimulus-controlled performance for all participants. These results represent another instance in which the amount of training is necessary, but not sufficient, for the development of stimulus control in temporal discriminations, and describe the effect of the number of consecutive trials within a block of training on temporal discriminations.

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This article reviews a few studies from our group reporting a counterintuitive finding on temporal learning and stimulus control in humans and rodents, and presents a new study on the topic.

Temporal Learning and Stimulus Control

The ability to estimate the passage of time in the seconds-to-minutes range, termed *interval timing*, is ubiquitous in nature. Humans and rodents, for example, are able to anticipate when reoccurring events will happen–and to adjust their actions accordingly. For example, in a 30-s fixed interval (FI) procedure, rats need only a few training sessions to show suppression of responding early in the FI and increase responding close to the end of the interval. Moreover, when different stimuli signal different intervals, the stimulus acquires control over responding. If a houselight signals a 30-s FI and a white noise signals a 60-s FI, rats increase their response rates earlier in the presence of the houselight than in the presence of the white noise. In this example, the stimuli (houselight and white noise) control performance in the sense that responding is initiated at the appropriate time as a function of the previous experience with those stimuli.

Different cognitive and mathematical models of timing and conditioning, such as the Rescorla-Wagner model (Rescorla & Wagner, 1972), Scalar Expectancy Theory (SET; Gibbon, 1977; Gibbon, Church, & Meck, 1984) or Learning-to-time (LET; Machado, 1997), suggest different intervening variables necessary for such temporal learning to develop. The input to these models are the number of pairings of each stimulus and interval trained, while the outcome would be the strength of the association between them (in the case of the Rescorla-Wagner model and LET) or the content stored in memory (in the case of SET). The prediction from these models is that performance progresses from no temporal discrimination and no stimulus control over responding early in training, to temporal discrimination and stimulus control over responding as the *amount* of training increases.

The Counterintuitive Finding

Along these lines, our group initially wanted to study the speed in which associations between stimuli and intervals are formed, and whether the training order of the different stimuli and intervals could affect that speed of learning. What we observed is that, in some cases, rats and people learned those associations as predicted by timing and conditioning models. However, to our surprise, there were instances in which they did not learn the associations even after hundreds of trials of training of the same stimuli and intervals (e.g., Caetano, Guilhardi, & Church, 2012). Specifically, we observed that stimulus control could not be established depending on the *order* of training (as opposed to the *amount* of training) of the different pairs of stimuli and intervals. A summary of these findings is presented below for rats and humans.

Acquisition of Stimulus Control in Rats

In experiments using signaled fixed-interval discriminations (Caetano, Guilhardi, & Church, 2007, 2012), groups of rats had the same amount of training on multiple signaled temporal discriminations that differed only on the sequence in which they were trained. For some rats, the temporal discriminations were presented intermixed within each experimental session, while for other rats, they were trained successively in blocks of multiple sessions. Although performance at the end of training was similar between the two groups, rats in the blocked condition showed no immediate stimulus-controlled performance when presented with intermixed trials.

More specifically, the surprising failure to acquire stimulus control under certain training conditions was based on rats trained on three fixed-intervals (30 s, 60 s, and 120 s) and signaled by three stimuli (Guilhardi & Church, 2005) for 30 sessions containing 60 trials each. A fixed-interval trial started with the onset of the stimulus. After the target duration had elapsed (30-, 60-, or 120-s depending on the stimulus presented), the first response (break of a photo beam in the food cup) produced the delivery of the food and termination of the stimulus. Trials were interspersed with a 20 s intertrial interval. Training of the three intervals occurred either intermixed within a session (intermixed group) or in blocks of 10 sessions for each interval (blocked group). Asymptotic performance averaged across the last cycles of training of each interval was similar across the two groups (intermixed and blocked) and resembled the fixed-interval scallop function (response rate gradually increased as a function of time from stimulus onset and the increase was related to the interval duration).

After the 30-sessions training, all rats continued with training on the three signaled intervals intermixed within a session. Secondary data analysis (Caetano et al., 2007) of the first few cycles of each of the intervals (transfer test) during this new treatment for the blocked group showed that stimulus control was not acquired. The rats from this group showed response rate gradients that increased as a function of time but were almost identical for the three stimuli and intervals, that is, the rats did not learn their relationship. These results suggested that although performance at the end of training was similar across the two groups of rats, what they have learned was not.

The experiment described above, however, did not eliminate the possibility that the failure to observe differential performance across stimuli for the blocked group during the transfer test was actually due to a disruption caused by a change in the training procedure (from training trials with only one stimulus to a transfer test with multiple stimuli within the session) and perhaps not related to problems in the acquisition of stimulus control. Given that during the transfer test it was the first time those rats in the blocked group were presented with the three-intervals within a session, it is plausible that the novel situation could have interfered with performance during the first few trials of this first session.

Results from another set of experiments, however, suggest this is not the case (Caetano et al., 2012). The authors trained rats on the same three fixed-intervals signaled by different stimuli for 35 sessions each containing 60 fixed-interval trials. In this experiment, however, one of the three signaled fixed intervals was trained on each day. Analysis of the last cycles of each session suggested stimulus controlled fixed-interval performance. However, the first few cycles of each of the sessions did not. The rats did not memorize the stimulus-interval discriminations; rather, they rapidly adjusted their performance to the daily fixed-interval durations. Because the change in intervals occurred daily for 35 days, it is implausible that disruption produced these effects.

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 to as *stimulus control*. In both the intermixed and blocked conditions, the rats had the same number of stimulus-interval associations trained, but they occurred in different orders. In the intermixed conditions, they learned the relationship between the stimuli and intervals; but in the blocked condition they did not learn the relationship between the stimuli and the intervals.

Acquisition of Stimulus Control in Humans

In order to further explore these effects produced by training order, Guilhardi et al. (2010) used a temporal discrimination task that has successfully being adapted to humans. This adaptation of the standard peak interval procedure (Bitterman, 1964; Catania, 1970; Roberts, 1981) 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 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 (black, green, blue), 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 (color of the screen) remained visible anywhere else in the screen. During these trials, the position of the target in 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, which was signaled by a brief tone.

Response rate as a function of time approximated a normal function with peak rate at around the time at which the target hit the middle of the screen. The peak time and standard deviations were linearly related to the interval duration, and, therefore, the coefficient of variation was approximately constant. These findings were consistent across participants, they provided evidence for well-established principles of timing (Gibbon, 1977, 1991), and were used to make inferences about underlying intervening processes. Thus this procedure was ideal for the investigation of the effects of training order on performance and learning of multiple temporal discriminations in humans.

Using the procedure described above, Guilhardi et al. (2010) evaluated the effects of within-session training sequences and discrimination difficulty on learning and performance in humans. Twenty-four participants were trained on three signaled fixed intervals that were trained for 60 trials (30 regular and 30 peak trials). The stimulus-interval associations were either presented in blocks of 60 trials for each stimulus or intermixed throughout the session. In addition to training sequence, each group had either easy or difficult stimulus discriminations, which was measured by the difference in luminance across the three stimuli (background colors). After training, all four groups of six participants (Blocked-easy, Blocked-difficult, Intermixed-easy, and Intermixed-hard) showed response rate gradients that were related to the stimulus-interval association presented.

Following training, all participants had a transfer test which consisted of 30 peak trials with stimuli-intervals associations intermixed across trials. The transfer test results showed that both Intermixed-easy and Intermixed-difficult groups as well as the Blocked-easy group showed stimulus controlled performance early in the transfer test, thus memorized the intervals. The Blocked-difficult group, however, showed similar performance across the three intervals early in the transfer test, and therefore did not memorize the stimulus-interval associations.

The surprising results from Guilhardi et al. (2010) were the different learning between the Blocked-easy and Blocked-difficult. Consistent with results obtained with rats (Caetano et al., 2007; Caetano et al., 2012) the Blocked-difficult group did not show memorization of the stimulus-intervals associations. The results for the Blocked-easy group, however, are not consistent with those results obtained for rats in which training in blocks of trials did not produce learning when the discrimination was considered easy (stimuli of different modalities, in some cases).

Guilhardi et al. (2010) showed that discrimination difficulty also modulates what is learned when stimulus-interval associations are trained in blocks of trials. In the present study, we investigated if the number of consecutive trials in each block (i.e., block size) can also determine whether or not the different stimuli acquire control over temporal performance.

Method

All experimental protocols were approved by the Ethics Committee at UFABC and all participants provided written informed consent.

Participants

Seventy-five undergraduate students, 38 men and 37 women, ranging from 18-30 years old, from Federal University of ABC participated in the experiment. Fifty undergraduate students (29 men and 21 women, ranging from 18-30 years old from the Federal University of ABC) were participants who met the criteria for the experiment. Twenty-five others did not meet the criteria of learning the task (see *Test after intermixed training*), responding at more than 10 shots per minute during peak trials, and completing the task. The low response rates on peak trials were presumably due to participants attempting to optimize performance: participants excluded from the analyses under this criterion reported refraining from shooting during peak trials to avoid losing points for missing the target.

Equipment

The experiment was conducted in a small room isolated from external noise. Participants sat in front of a computer with a color monitor. Responses were made on a Dell keyboard. The computer monitor was a 15-in IBM E74 CRT set to 1024 x 768 pixels resolution and 85 Hz refresh rate. Auditory stimuli were presented through a pair of Sennheiser HD 25-1 II dynamic closed stereo headphones. The computer was equipped with a 2.53 GHz Intel Xeon E5630 processor, 6 GB of RAM memory, and NVidia Quadro NVS 295 video card. The experimental procedures were programmed in Matlab (R2014a) using the “PsychToolBox” library (Psychophysical Toolbox; www.psychtoolbox.org). All behavioral events were recorded with a 1-ms resolution.

Procedure

Participants were asked to sit in front of the computer monitor and presented with a target that consisted of five concentric circles colored red, white, red, and white, with a black central circle (bull's eye), as shown in Figure 1a. 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.

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 half-way across the monitor was 2 s, 2.82 s (the geometric mean of the 2- and 4-s intervals), or 4 s after the click, depending on the color of the background screen. These intervals 2, 2.82, and 4 are referred to as *short*, *intermediate*, and *long* intervals.

All shots were presented at the center of the screen and occurred when the participants pressed the right *control* key of the computer keyboard. Each shot was signaled by a 0.1-s yellow dot (5 pixels radius), which appeared in the center of the screen (on or off the target, depending on the target position at the time of the shot). Thus, participants could miss the target by responding either too early or too late, and could hit the target by responding at the time it was passing through the center of the monitor. At the end of each trial, a black screen was presented with a summary of the points obtained in the current trial, along with their accumulated score up to that trial. Participants were rewarded with 5 points for each shot in the central black circle; 1 point for all other shots on target; and -1 point for all shots that missed the target.

The short, intermediate, and long intervals (2, 2.82, and 4 s) were signaled by three different background colors (light, middle, and dark green, respectively; Figure 1b). For the background colors, hue (H) and saturation (S) were always constant at 82 and 56, respectively. Lightness was set at 60, 49, and 40 for the light, middle, and dark green, respectively. The choice of background colors was based on previous work (Guilhardi et al., 2010).

Two types of trials occurred. During regular trials, the trajectory of the target was visible on the computer screen. During peak trials, a white horizontal bar obscured the trajectory of the target and the yellow dots (Figure 1a), but feedback about performance in the trial was still shown on the screen. Therefore, during peak trials, participants could not visualize the location of the target and had to estimate its position on the screen from the time of the initial auditory stimulus (click) in order to hit it. Participants were trained for one session on this shooting task, which consisted in 450 trials divided in two training and testing phases, as described below.

Phase 1 – Blocked training (trials 1-180). During Phase 1, each of the three interval-color pairs was trained for a total of 60 trials. However, participants were divided into five groups (n = 10) and, depending on group assignment, each of the three interval-color pairs was trained in blocks of 10, 20, 30, or 60 consecutive trials (groups G10, G20, G30, and G60, respectively; an additional control group, G1, was formed and is described at the end of this section). The order of the blocks was chosen pseudo-randomly, with the constraint that, where applicable, two consecutive blocks of the same interval-color was not allowed.

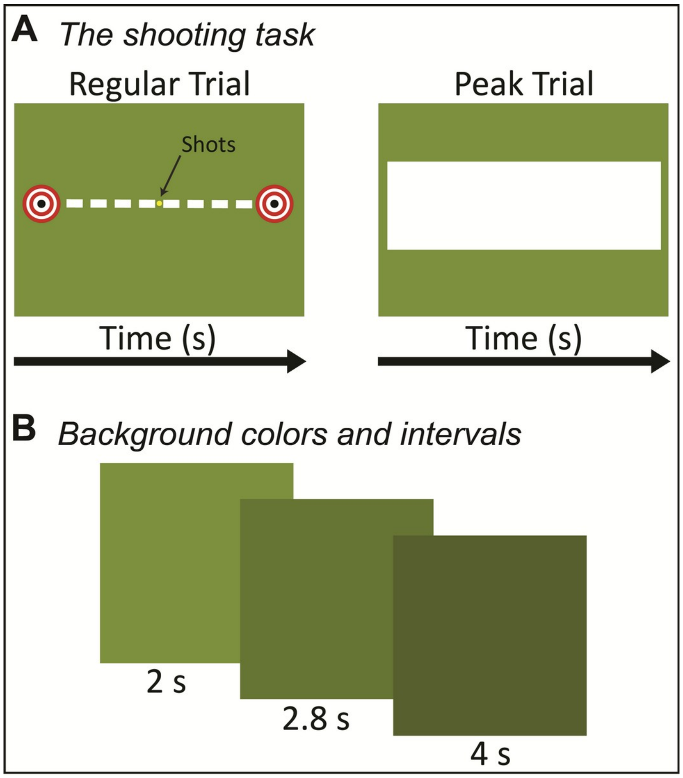

Figure 1. (A) Training procedure. A target moved from left to right across the center of the screen. Presses to the ctrl key delivered shots at the center of the screen. During regular trials (left panel), the target remained visible. During peak trials (right panel), the target and its trajectory across the screen were masked by a white rectangle. (B) The target could reach the center of the screen after 2 s, 2.8 s or 4 s after it started moving. The different speeds were signaled by three different background colors, light, middle, and dark green, respectively.

Therefore, the total amount of training of each interval-pair was identical across groups (60 trials per pair), but the number of consecutive trials of each pair (i.e., block size) differed across groups: Participants in G10 were trained for a total of 60 trials of each pair, but in pseudo-randomly ordered blocks of 10 consecutive trials each; participants in G20 had 3 blocks of 20 consecutive trials of each pair; participants in G30 had 2 blocks of 30 consecutive trials of each pair; and participants in G60 had one block of 60 consecutive trials of each interval-color pair. Regardless of block size, the first 10 trials of each interval-color pair consisted of regular trials and the next 50 trials consisted of 30 regular trials and 20 peak trials, randomly ordered.

Note that in Phase 1 there are two possible ways to estimate the location of the target during peak trials and, therefore, perform well in the task. The first is to learn the relationship between colors and target speeds. The second is to shoot at approximately the same time as in previous regular trials within each block of consecutive trials, with no need to attend to the current background color.

Test after blocked training (trials 181-225). In order to assess whether or not participants in each group learned the relationship between background colors and intervals during blocked training, 45 test trials were presented to participants immediately after training in Phase 1. Test trials consisted in randomly ordered peak trials (15 trials of the short, intermediate, and long intervals). Because the different interval-color pairs were presented intermixed during these test (peak) trials, and because the trajectory of the target was masked, the background color was the only cue to target speed and, consequently, to the time in which the target would reach the center of the screen.

At the end of these test trials, participants were allowed to take a short break (2-3 min), after which training in Phase 2 commenced.

Phase 2 – Intermixed training (trials 226-405). During Phase 2, participants from all groups received the same training schedule, in which the three interval-color pairs were trained for a total of 180 trials (60 trials each), but the 180 trials were randomly ordered (intermixed). The first 30 trials were regular trials, with 10 trials of each pair randomly ordered. The next 150 trials consisted of 30 regular and 20 peak trials of each of the three interval-color pairs randomly presented.

Test after intermixed training (trials 406-450). In order to assess whether or not participants in each group learned the association between colors and intervals after the intermixed training, 45 test trials were presented to participants immediately after training in Phase 2. These test trials were identical to those presented after training in Phase 1 and described above.

Note that, in contrast to blocked training in Phase 1, the only possible way to perform well in Phase 2 is to learn the relationship between colors and target speed, since the three pairs are presented intermixed throughout this phase. Therefore, Phase 2 served as a control condition to ensure that (a) participants could discriminate between the different background colors, and (b) to ensure that they were able to learn the associations between colors and intervals. As described in Materials and Methods, participants who failed to demonstrate learning of those associations after training in Phase 2 were excluded from the analyses. Finally, to rule out a possible effect of amount of training between Phase 1 and Phase 2 on performance after Phase 2, participants in one additional experimental group (G1) were trained with the intermixed training arrangement in both phases.

Data analysis. Performance during test trials, both after blocked training in Phase 1 and after intermixed training in Phase 2, was analyzed. Mean responses per minute (RPM) as a function of time since onset of target movement was used to describe participants' performance. For statistical comparisons, individual temporal gradients were averaged over the last 15 peak trials for each interval-color pair (i.e., the entire set of test trials following each training phase), and fitted with the best normal function in Matlab. The absolute horizontal distances between means from the normal fits (i.e., fitted peak times) were summed and statistically compared across groups in a one-way ANOVA. For the analysis of individual performance within each group, an evaluation of the percentage of participants for whom the short and long peaks fell inside a 50% interval window around its scheduled time (i.e., between 2.5 and 3.5 s for the short interval, and between 4 and 5 s for the long interval) was done. This window was used as a reference to where peaks should fall assuming participants used the background color to estimate the location of the target during peak trials.

Results

Performance is Different Across Groups After Blocked Training in Phase 1

Responses (shots) per minute as a function of time from onset of target movement, averaged across the 45 test trials after Phase 1 and across all participants, are shown in Figure 2 for groups G1, G10, G20, G30, and G60 (panels A to E, respectively). Dashed lines denote the time at which the target reached the center of the screen during short, intermediate, and long intervals (black, red, and blue lines, respectively). For participants in G1 (intermixed training in both phases), the times at which responses reached the maximum rate (i.e., peak times) for the three interval-color pairs were clearly distinct (i.e., the three curves are clearly separate). However, performance in test trials after Phase 1 became more similar across interval-color pairs as the plots progress from G1 to G60. For participants in G60 (Figure 2E), the three curves are highly superposed.

To quantify this failure to distinguish between the different interval-color pairs across groups, individual sums of the absolute distances between the three peaks (i.e., abs[P2-P1] + abs[P3-P1] + abs[P3-P2], where P1, P2, and P3 are the time at which the normal fits for response rate was maximum for the short, intermediate, and long intervals, respectively) were computed. Figure 2F shows this sum of absolute distances averaged across participants in each group. As suggested by panels A to E, there was a gradual approximation of the three curves across groups, from low overlap (G1) to high overlap (G60), One-way ANOVA, $F(4,45) = 2.99$, $p = 0.029$, suggesting that, depending on block size, participants may or may not be able to use the background color to correctly predict when to shoot at the hidden target.

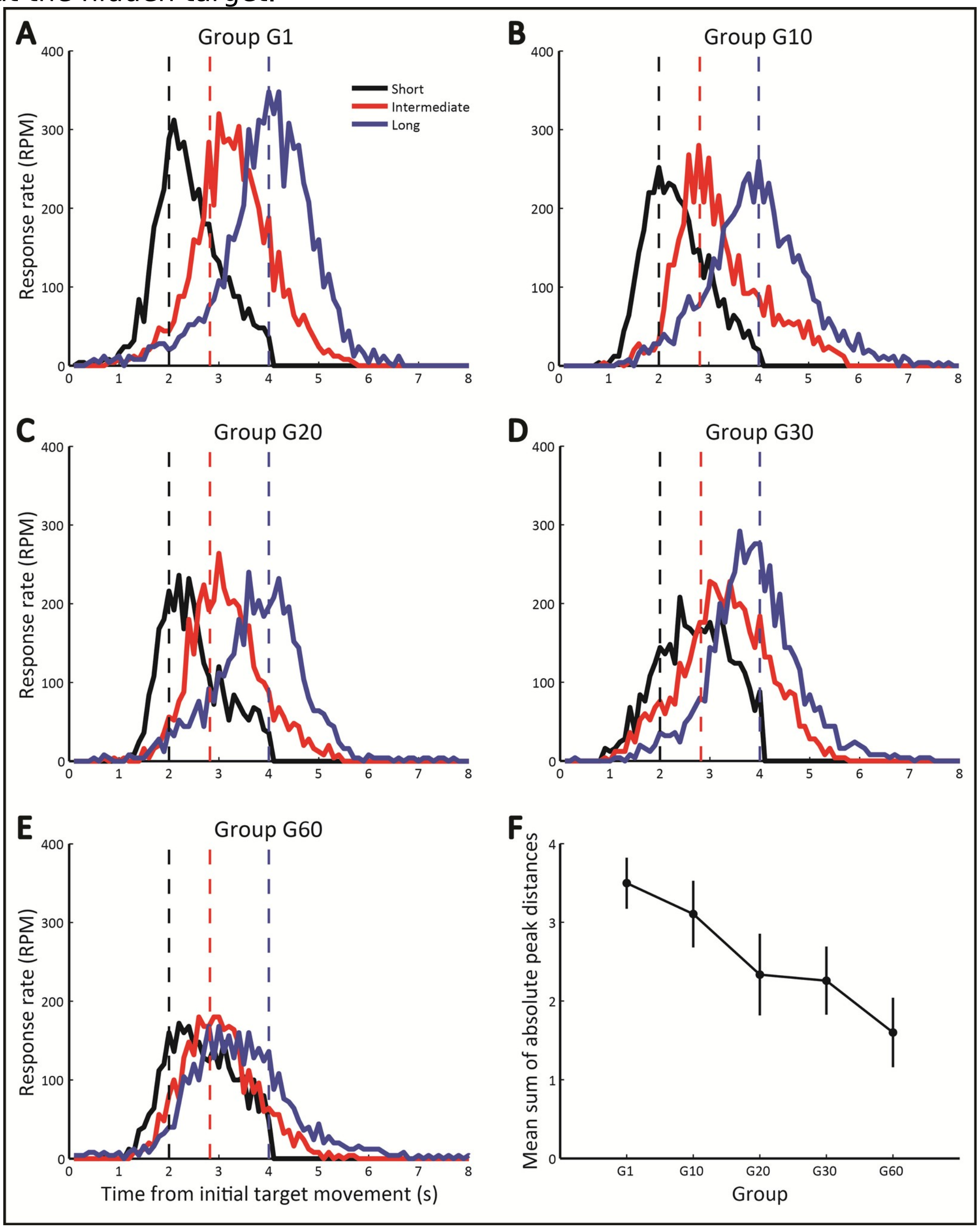

Figure 2. *Performance during test (peak) trials after training in Phase 1 for groups G1 to G60* (panels A to E). Black, red, and blue solid lines are responses (shots) per minute as a function of time from initial target movement during short, intermediate, and long trials, respectively. Dashed lines

represent the time at which the target was at the center of the screen in each trial type. (F) Sum of absolute peak distances averaged across participants in each group. The higher the sum, the more separate the three peaks. Error bars are SEM.

Performance is Similar Across Groups After Intermixed Training in Phase 2

In Phase 2, all participants were trained with an intermixed order of trials with the different interval-color pairs. During test trials following this training, response gradients were distinct for the short, intermediate, and long intervals for all groups (Figure 3A-E). Moreover, sums of absolute distances averaged across participants were similar for the all groups (Figure 3F; One-way ANOVA, $F(4,45) = 0.14$, $p = 0.968$), suggesting that participants in all groups were able to use the background color to correctly predict when to shoot at the hidden target.

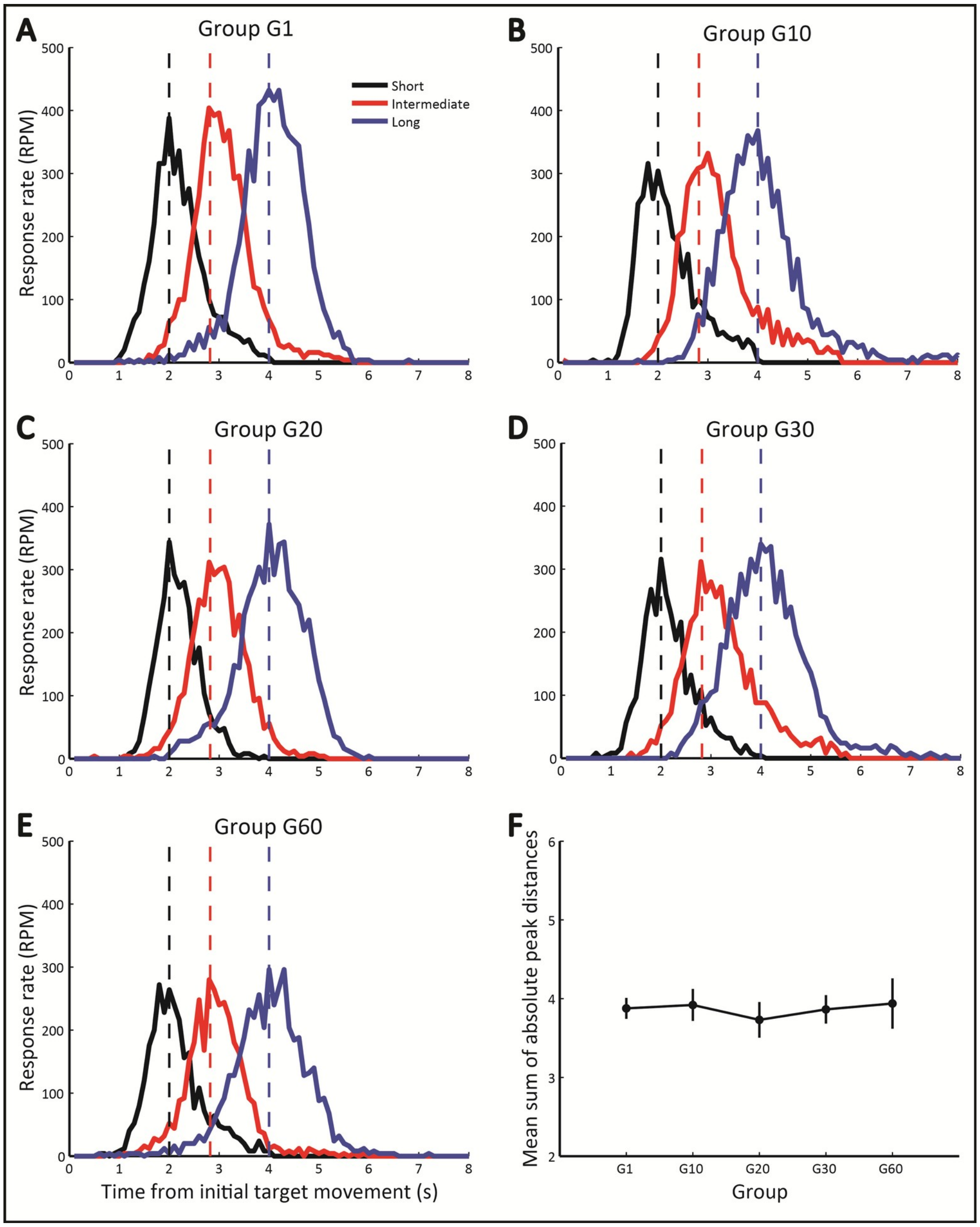

Figure 3. *Performance during test (peak) trials after training in Phase 2 for groups G1 to G60* (panels A to E), and sum of absolute peak distances averaged across participants in each group (F). Details are identical to those described for Figure 2.

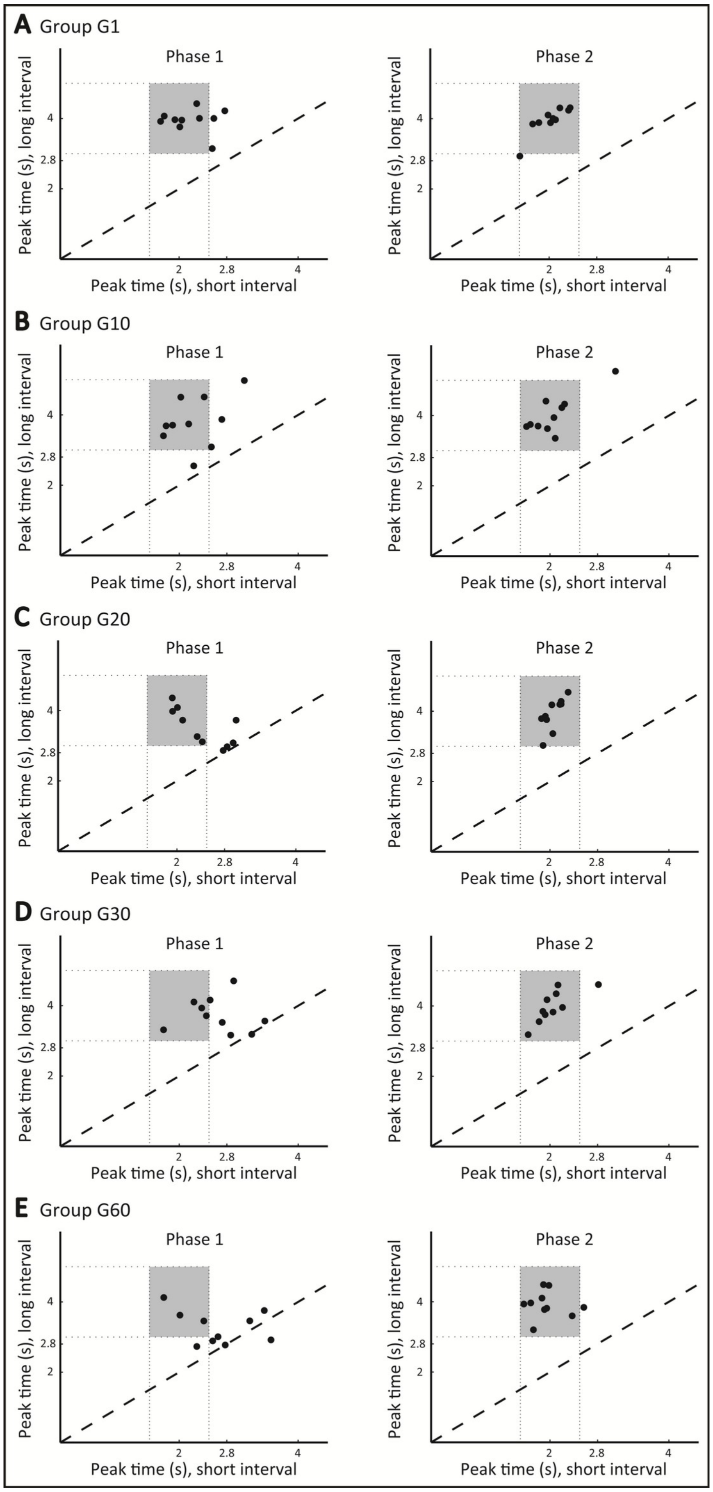

Figure 4. *Individual peak times (black dots) for the short (2 s) interval plotted against peak time for the long (4 s) interval for groups G1 to G60* (panels A to E), during test trials after Phase 1 (left column) and after Phase 2 (right column). Gray squares denote scheduled peak times ± 25% of peak times (from 1.5-2.5 s for the short interval, and from 3-5 s for the long interval). The diagonal dashed line is the identity line. Data points should fall close to the identity line in the case of no stimulus-controlled

performance, and fall away from the identity line and into the gray squares when there is stimulus-controlled performance.

Analysis of Individual Performance

The apparent gradual change in interval discrimination across groups in the test trials after Phase 1 could either be representative of individual performance in each group, or it could be due to a gradual change in the percentage of participants for whom the different colors became associated with the different intervals. To determine the source of that gradual change, peak time for the short interval was plotted against peak time for the long interval for each participant in each group (Figure 4, panels A to E) during test trials after Phase 1 (left column) and after Phase 2 (right column). The gray squares denote scheduled peak times ± 25% of peak times (i.e., from 1.5-2.5 s for the short interval, and from 3-5 s for the long interval). The diagonal dashed line is the identity line. If participants were not able to discriminate between the two interval-color pairs in the test trials, their representative dots should fall close to the identity line. A progressively larger percentage of participants falling close to the identity line, and a smaller percentage of participants who fell into the gray squares, were observed from G1 to G60 in the test trials after blocked training in Phase 1. This suggests that most participants in G1 used the different colors to perform correctly in test trials, while only a few did so in group G60. After the intermixed training in Phase 2, however, performance was very similar across all groups, with virtually all participants falling into the gray squares. This suggests that, regardless of the initial training arrangement, all participants were able to use the different colors to perform correctly in test trials after the intermixed training.

Discussion

There is great similarity between rats and humans in the conditions under which different stimuli acquire control over temporal performance, as reviewed in the introduction. Those studies suggest that the amount of training is necessary, but not sufficient, to predict when stimulus-controlled performance will develop. They also suggest that the order in which the different temporal discriminations are trained determine whether or not stimulus control will be established.

Following that review, the present experiment extends those findings and suggests that a factor that affects the development of stimulus control in temporal discriminations is the number of consecutive trials trained within a block of trials. Participants learned the association between the different background colors and target speeds only when those pairs were trained intermixed in Phase 1 (group G1; Figure 2A). This means that, given the background color, participants in G1 were able to perform well in the following intermixed test trials in which the trajectory of the target was masked. However, although the overall amount of training was held constant across groups, as the number of consecutive trials within each block (i.e., block size) increased in Phase 1, gradually more and more participants did not show stimulus-controlled performance in the test trials (groups G10 to G60; Figure 2B-E).

Although many participants in groups G10 to G60 failed to demonstrate stimulus-controlled performance with blocked training after Phase 1, participants greatly improved performance and were able to correctly predict the location of the target given the background color in the test trials following intermixed training in Phase 2 (Figure 3). This suggests that those participants (a) were able to discriminate between the different colors, and (b) were able to use that information to guide responding. Because participants in G1 readily showed stimulus-controlled performance in the test trials after Phase 1, it is unlikely that differences in the amount of training between Phases 1 and 2 for groups G10 to G60 can account for the development of stimulus-controlled performance illustrated by Figure 3.

But what accounts for the difference in performance between groups during Phase 1, where the same number of trials were trained, but in different block sizes? One way to answer this question is to consider what cue could be used by the participants to predict the speed of the target when this speed changed in every trial (intermixed trials), vs. when it changed only a few times during training (blocked trials). When the different interval-color pairs were trained intermixed, the only possible way to predict the location of the target during peak trials was to use the background color as a discriminative stimulus for the different target speeds. However, when trained in blocks of many consecutive trials, participants could also rely on the speed of the target in the previous trials within that block, and use that information to predict the speed of the target in the current trial. In this case, there would be no need to attend to the background color. The use of this alternative cue would lead to good performance in peak and regular trials within each training block, but also lead to an inability to hit the target in the intermixed test trials presented after Phase 1. Moreover, the prediction in this case would be that the longer the block of trials, the more reliable is the previous trial as a cue for target speed in the current trial. In fact, this is exactly what was observed between groups G10 to G60, with participants performing gradually worse across the intermediate groups (presumably gradually relying less and less on background color, and more on the previous trial).

It is important to note that even for participants in the longest block (G60), the different stimuli still were reliable cues to target speed, which suggests some sort of competition between cues to control behavior. Therefore, one way of interpreting these results, as previously suggested (Caetano et al., 2012), is that the temporal features of the previous trial *overshadowed* the stimulus. Usually, in experiments on overshadowing, two stimuli compete for control of performance (e.g., Jennings, Bonardi, & Kirkpatrick, 2007; McMillan & Roberts, 2010). However, since a time interval itself can be viewed as a stimulus (Ferster & Skinner, 1957; Williams & LoLordo, 1995), it is possible that the memory of the target speed in the previous trials may be more salient than the background colors used in the current experiment. Support for this possibility was given by Guilhardi et al. (2010; reviewed in the introduction), in which blocked training of three interval-color pairs with colors that were easier to discriminate than those used in the current experiment in fact led to stimulus-controlled performance. The larger discrepancy between the colors in Guilhardi el al. (2010) could have made the background colors more salient cues than the experience with the temporal intervals in the previous trials.

Conclusions

Studies reviewed in this manuscript describe the conditions under which different stimuli acquire control over temporal performance in rats and humans. In general, they describe great similarity in these conditions between species, and point to the conclusion that the amount of training is necessary, but not sufficient, to predict when stimulus-controlled performance will develop. Importantly, the order in which the different discriminations are trained also determine whether or not stimulus control will emerge. Along these lines, the experiment herein described extends these results and suggests that block size is an important factor that modulates the development of stimulus control in temporal procedures.

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