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RHESUS MONKEYS (*Macaca mulatta*) MAINTAIN
LEARNING SET DESPITE SECOND-ORDER
STIMULUS-RESPONSE SPATIAL DISCONTIGUITY

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In many discrimination-learning tests, spatial separation between stimuli and response loci disrupts performance in rhesus macaques. However, monkeys are unaffected by such stimulus-response spatial discontinuity when responses occur through joystick-based computerized movement of a cursor. To examine this discrepancy, five monkeys were tested on a learning-set task that required them to touch computer-graphic "levers" (which differed in location across experimental phases) with a cursor in order to select an associated test stimulus. The task produced both first-order (joystick and lever) and second-order (lever and stimuli) spatial discontinuity between the stimuli to be discriminated and the discriminative response. Performance was significantly better than chance for all lever locations including locations in which selection of the correct lever required moving the cursor away from the positive stimulus. Thus, rhesus macaques do not attend simply to the region around the cursor in these computerized tests, but rather they attend to relevant stimulus loci even when these are discontinuous with response and reward areas.

Despite being prolific learners in standard discrimination tasks, rhesus macaques (*Macaca mulatta*) traditionally have shown great difficulty in learning two-choice discrimination tasks when there was stimulus-response (S-R) spatial discontinuity (see Meyer, Treichler, & Meyer, 1965). For example, when objects to be discriminated were 6 inches away from the reward and the site of the response, rhesus monkeys did not exceed chance levels of responding (Murphy & Miller, 1955). Murphy and Miller (1958) tested 5 rhesus using the Wisconsin General Test Apparatus (WGTA), an apparatus that allowed monkeys to make discrete responses to a tray containing multiple wells with stimuli above them, one of which (the S+) had a food reward hidden under it. The

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apparatus allowed researchers and the monkeys to manipulate objects independent of any influence on each other. The discontinuity of cue, reward, and response all were manipulated with a 7-inch space between any two stimuli. Learning occurred in the condition in which the cue was contiguous with either the response or the reward but did not occur when the cue was not spatially contiguous with the reward or response. Meyer, Polidora, and McConnell (1961) found that performance of monkeys was poorer when responding to stimuli discontinuous with an activating panel in a computerized apparatus than when the response loci were contiguous with the cue stimuli. Stollnitz (1965) noted that the rate of learning a single discrimination is inversely related to the distance between cue and response loci as the degree of separation greatly affects performance. More recently, Iwai, Yaginuma, and Mishkin (1986) found that differences in learning occurred with small differences in cue-response separation (see also Yaginuma & Iwai, 1986).

S-R spatial discontinuity effects are relevant in the learning performances of species other than monkeys. Spence (1937) noted that in discrimination learning by chimpanzees spatial contiguity of response and stimulus and of response and reward was important in rapid learning. Jenkins (1943) also reported that discrimination performance in chimpanzees was greatly improved when the distance between the stimuli and the site of the response was reduced from 7.5 inches to 1.5 inches. Murphy and Miller (1959) observed children from Grades 1 to 4 in a discrimination task. Cues were either separated or close to response loci and reward loci. In the separated condition, the cue was 6 inches above the response locations. The response and reward were contiguous in both conditions. Learning was significantly retarded in the cue-separated condition.

Stollnitz and Schrier (1962) suggested that spatial discontinuity problems could be overcome with suitable apparatus. One way would be to use gradual separations of discriminanda and manipulanda. Stollnitz and Schrier presented either gradual spatial distancing between discriminanda and manipulanda or immediate 7-inch separation during a discrimination task, and they found that even animals starting with 7 and 18 inches of separation reached criterion (and were almost perfect for those five criterional sessions). There also was no systematic decrease in performance as a function of the increase in separation for the gradual group of monkeys. Three monkeys also learned a reversal at the 18-inch separation. Discriminations learned with one separation could be transferred to larger separations. However, increasing spatial separation by 4 inches or more in one jump seriously impaired performance.

McClearn and Harlow (1954) used stimuli separations of 0, 1, 2, and 4 inches using a modified WGTA. Two color blocks were the stimuli throughout the experiments, and white was always the correct stimulus. Although all four rhesus monkeys that were tested were significantly better than chance for each degree of separation, the greater the separation between response and cue loci, the greater the decrement in performance. Schrier, Stollnitz,

and Green (1963) also used a black-white discrimination task with S-R separation titrated after two correct responses. Of the 5 monkeys observed, 4 were successful with separations up to 12 inches. Thus, S-R separation can be overcome using a titration method with the WGTA.

Another successful means of overcoming S-R spatial discontinuity by rhesus monkeys has involved joystick-based computerized tests (Richardson, Washburn, Hopkins, Savage-Rumbaugh, & Rumbaugh, 1990; Rumbaugh, Richardson, Washburn, Savage-Rumbaugh, & Hopkins, 1989; Washburn, Hopkins, & Rumbaugh, 1989). Rumbaugh et al. (1989) reported that two rhesus monkeys mastered control of a joystick to respond to a variety of stimuli on a computer monitor despite the fact that the joystick was located up to 6 inches away from the video screen. Rumbaugh et al. suggested that S-R spatial discontinuity affected performance only to the extent that the monkeys attended to the movement of their hands. Monkeys failed to learn because they could not be rewarded for observing relevant cues when they were looking at their hands instead of those cues. However, when attention was shifted away from the hands and toward the cursor on the monitor, the monkeys had to attend to and respond to loci independent of the location of the monkeys' hands. Otteson, Sheridan, and Meyer (1962) also reported that monkeys monitored their fingers closely during discrimination tasks. When a partition was raised between the response loci (touching two small food cups) and the discriminative stimuli (letters), 6 of 12 monkeys learned as compared to no learning when the partition was absent. The remoteness of the responses from the cue stimuli in and of itself was not a consequential factor.

Thus, S-R spatial discontinuity effects can be overcome provided titrations in separation length or some means of dissociating attention to hand movements is used. However, little is known about whether monkeys can overcome second-order S-R spatial discontinuity. In all prior research, the S-R spatial separation was of a single order. In WGTA tasks, the monkeys touched spatially discontinuous response loci with the hand. In joystick tasks, there is S-R spatial discontinuity between hand and response loci, but response loci typically also are cue loci. The joystick-based apparatus, however, allows for the possibility of second-order S-R spatial discontinuity. If the response and cue loci on the monitor are spatially discontinuous (first-order) and response movement is joystick mediated (second-order), the monkeys must overcome spatial discontinuity on two fronts.

Such a task is particularly interesting because of the possibility that rhesus monkeys, when using joysticks, simply transfer their attention from the fingertip to the cursor. Thus, they act as if the cursor is simply an extension of the finger, in which case learning occurs best with spatial contiguity because the animal most effectively attends to those things closest to the finger during responding (Shuck, 1960). If this is the case, S-R spatial discontinuity between response and cue loci on the monitor should disrupt performance even if the cursor now acts as a surrogate

finger for the animal. However, if performance remains high with such spatial discontinuity, this may indicate that the computerized apparatus frees the monkeys from the constraints of cue and response loci typically found with the WGTA.

In the following experiments, 5 rhesus monkeys were presented with a learning set task (Harlow, 1949). Initially, the monkeys had to move the cursor into contact with one of two stimuli on the monitor. However, second-order S-R spatial discontinuity was introduced when two "levers" were presented on the screen. Each lever was located on the same vertical half of the monitor as its corresponding cue stimulus, and now the monkeys had to contact the lever in order to make a response. The locations of these levers were manipulated in Experiment 1 (with 2 monkeys) in a sequence in which the levers gradually moved farther from the cue stimuli and eventually were placed below the cursor on the computer monitor such that the monkeys had to move the cursor away from the cue stimulus in order to select the corresponding response lever. In Experiment 2, fewer gradual lever positions were introduced to 3 additional monkeys to determine the effect of more immediate S-R spatial discontinuity between response and cue loci.

It is important to note that the computerized task does not allow the monkeys simply to attend to these levers as the response loci across trials, because the S+ within the learning set problem shifts locations (left and right) across trials within a problem. In other words, the monkeys cannot learn only that the left lever or right lever is the correct stimulus, because which lever is the correct lever depends on the location of the actual S+ on each trial. Therefore, a specific lever cannot operate as part of the S+, but it must operate only as a response location after the true S+ is determined. This makes the task very different from others in animal learning studies in which the effective stimulus is located some distance from the location at which a response is made (e.g., choice points in mazes) because in learning set tasks the effective stimulus is not stable across trials as it is in those tasks, and we assume this level of task complexity has contributed to the consistent difficulties encountered with manual apparatus in which cues and response loci are spatial discontinuous.

Experiment 1

Method

Participants. Two rhesus monkeys (*Macaca mulatta*) were observed. They were members of a colony of macaques housed at the Sonny Carter Life Sciences Laboratory at the Language Research Center of Georgia State University. The monkey Baker was 20 years old, and the monkey Willie was 16 years old at the time of this experiment. These monkeys have extensive testing histories using the Language Research Center Computerized Test System (Rumbaugh et al., 1989; Rumbaugh & Washburn, 1993; Washburn, 1994; Washburn, Hopkins, & Rumbaugh, 1989, 1990, 1991; Washburn & Rumbaugh, 1991a, 1991b, 1992).

Apparatus. The computer on which trials were presented was a Compaq DeskPro with an attached Kraft Systems joystick. The program was written in Visual Basic for Windows. Correctly completed trials were automatically rewarded by the computer with single 97-mg Noyes food pellet rewards through use of an automated pellet dispenser (for more details of the computerized apparatus, see Richardson et al., 1990). Stimuli consisted of clip art images downloaded from the internet and from commercially available software.

Design and procedure. Each monkey initially performed a learning set task. At the start of each trial, two stimuli appeared, one in each of the top corners of the computer monitor. A cursor also appeared centered in the lower part of the monitor. The monkey could manipulate a joystick, using its hand, to move the cursor on the computer screen. When one of the two stimuli was contacted with the cursor, the stimuli and the cursor were removed from the screen. If the correct stimulus was selected, the monkey received a pellet and a tone sounded. If the incorrect stimulus was selected, a buzz sounded and a 10-s time-out was presented during which the monitor remained blank. The next trial then was presented. Each pair of stimuli was presented for six consecutive trials, and then a

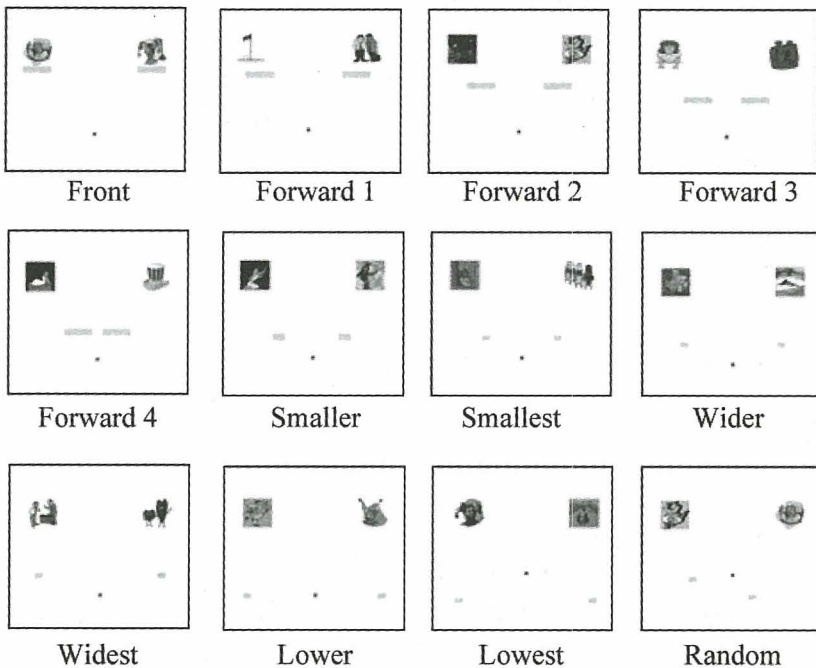


Figure 1. The lever positions. The small dot centered in the bottom portion of the screen (directly over the caption numbers) is the cursor. The cue stimuli are in the top left and top right corners of the monitors. The levers are the rectangular shapes that are in different locations in each image. The presented sequence for the positions progresses from left to right for each row.

new pair of stimuli was introduced. The member of each pair of stimuli designated as the correct stimulus (S+) was randomly determined by the program, and the stimuli were randomly assigned to the two locations on the monitor for each trial. None of the stimuli were reused at any time during the experiment (i.e., after being presented for six trials, those stimuli were not used again).

To reach criterion and progress to the second-order S-R spatial discontinuity condition, the monkeys had to be correct on at least 80% of the trials in ordinal positions two, three, four, five, and six within the six-trial problems for a block of 20 problems (120 trials total). When criterion was reached, the program then introduced second-order S-R discontinuity. To establish second-order S-R discontinuity, two "levers" were introduced that acted as the response loci for the corresponding discriminative stimuli on the same vertical half of the monitor. Initially, these levers were placed just below their corresponding discriminative stimuli. When the criterion (as defined above) was met at each successive position, the levers were moved farther away from the discriminative stimuli. In addition, the levers became smaller across subsequent positions. The levers then moved progressively closer to the respective edges of the monitor. The most difficult positions involved the levers being placed below the cursor on the monitor so that the monkeys had to move the cursor away from the discriminative stimuli to reach the respective levers for those stimuli. In the final position, the levers were placed randomly on each side of the monitor and were no longer symmetrical in relation to each other. There were 12 positions with second order S-R discontinuity (see Figure 1 for examples of all lever positions).

Results

Both animals met the criterion for all lever positions. The mean number of 120-trial blocks needed to reach criterion for Willie was 51.38

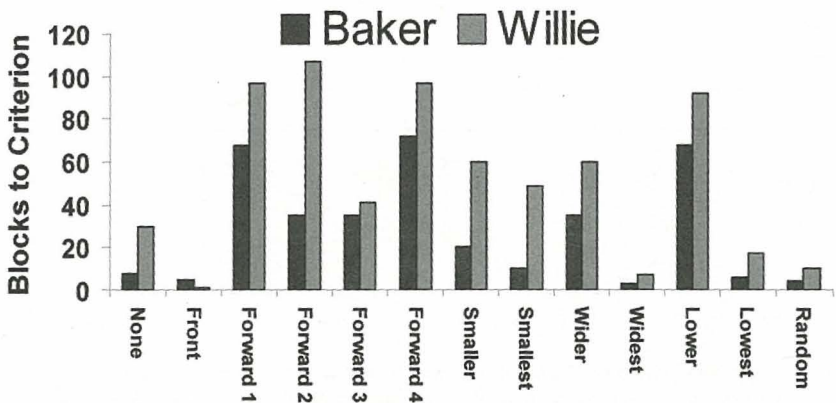


Figure 2. Number of 120-trial blocks to reach criterion at each lever position.

($SD = 37.67$). The mean number of 120-trial blocks needed to reach criterion for Baker was 28.38 ($SD = 26.27$). Thus, there was great variability in the number of 120-trial blocks needed to reach the criterion as a function of lever position (Figure 2). However, as compared to chance levels of responding, the monkey Willie was significantly better than chance (for Trials 2 through 6) on the first 120-trial block for all positions, all $\chi^2(1, N = 100) > 4.84, p < .05$. The monkey Baker was significantly better than chance (for Trials 2 through 6) on the first 120-trial block for all positions, all $\chi^2(1, N = 100) > 11.56, p < .01$ except the position Forward 1, $\chi^2(1, N = 100) = 3.24, p > .05$. For that lever position, Baker exceeded chance responding at a statistically significant level by the third block of 120 trials.

For monkey Willie (Figure 3), significant decreases in performance from the criterion-reaching block at one position to the initial block at

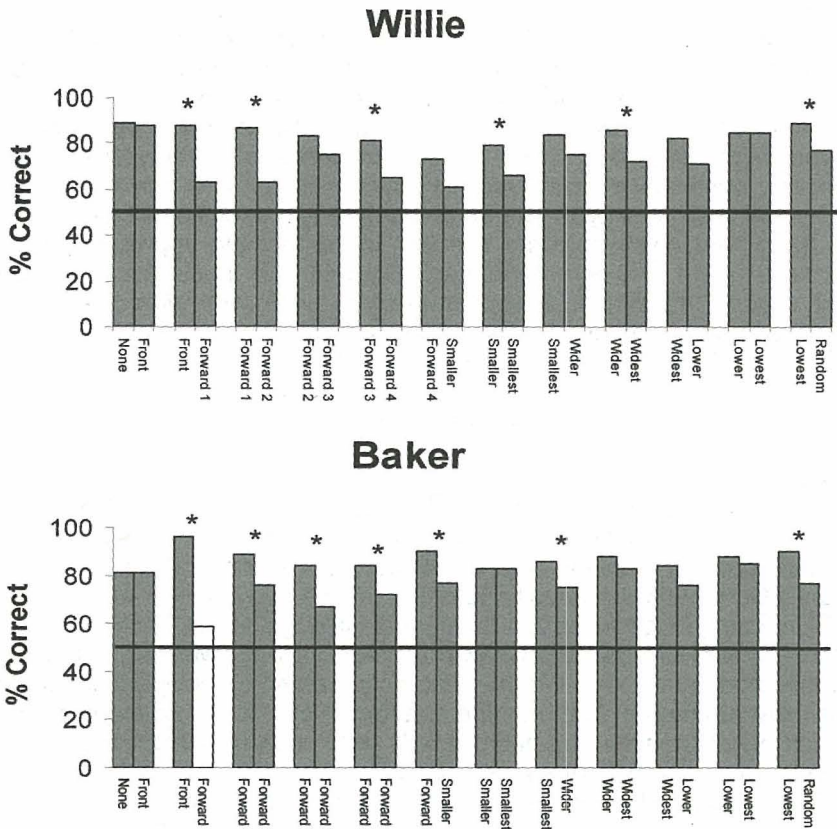


Figure 3. Comparison of performance at criterion-reaching trial block to first trial block at subsequent lever position for monkeys Willie and Baker. Chance is indicated with the horizontal line. Performance was significantly better than chance ($p < .05$) for all bars except the open bar for monkey Baker. * indicates a significant difference ($p < .05$) between two adjacent bars (criterion-reaching trial block and first trial block of subsequent lever position).

the next position occurred for the shifts between positions Front-Forward 1, $\chi^2(1, N = 100) = 16.89, p < .01$; Forward 1-Forward 2, $\chi^2(1, N = 100) = 15.36, p < .01$; Forward 3-Forward 4, $\chi^2(1, N = 100) = 6.49, p < .05$; Smaller-Smallest, $\chi^2(1, N = 100) = 4.24, p < .05$; Wider-Widest, $\chi^2(1, N = 100) = 5.91, p < .05$; and Lowest-Random, $\chi^2(1, N = 100) = 5.10, p < .01$.

For monkey Baker (Figure 3), significant decreases in performance from the criterion-reaching block at one position to the initial block at the next position occurred for the shifts between positions Front-Forward 1, $\chi^2(1, N = 100) = 39.25, p < .01$; Forward 1-Forward 2, $\chi^2(1, N = 100) = 5.85, p < .05$; Forward 2-Forward 3, $\chi^2(1, N = 100) = 7.81, p < .01$; Forward 3-Forward 4, $\chi^2(1, N = 100) = 4.19, p < .05$; Forward 4-Smaller, $\chi^2(1, N = 100) = 6.13, p < .05$; Smallest-Wider, $\chi^2(1, N = 100) = 3.85, p < .05$; and Lowest-Random, $\chi^2(1, N = 100) = 6.13, p < .05$.

Discussion

Both monkeys maintained learning set despite second-order S-R spatial discontinuity. Although various lever positions required a greater number of 120-trial blocks than did other lever positions before the criterion was met, even from the first block the monkeys performed at levels significantly better than chance for almost all lever positions. The last few positions were arguably the most difficult from the perspective of spatial discontinuity of cue and response loci because the cursor had to be moved away from the cue loci to contact the appropriate lever. However, both monkeys performed very well with these lever positions. In a second experiment, 3 naive monkey subjects were presented with a reduced number of lever positions so as to determine the effect of more immediate S-R spatial separation between levers and cue stimuli.

Experiment 2

Method

Participants. Three male rhesus monkeys (*Macaca mulatta*) were observed. The monkey Hank was 18 years old at the time of this experiment. This animal also came from the colony of animals at the Sonny Carter Life Sciences Laboratory, and he had a similar experimental history using joysticks as did the animals in Experiment 1. The monkeys Han (3 years of age) and Chewie (6 years of age) were new additions to this monkey colony, and they had only learned to use joysticks during the previous month. This was the first formal computerized experiment in which either monkey had participated, and it was also the first exposure to a learning set task for either monkey.

Apparatus. The same apparatus was used as in Experiment 1.

Design and procedure. The same program was used as in Experiment 1. However, these 3 monkeys were not exposed to all second-order S-R spatial discontinuity lever positions as were the monkeys in Experiment 1. Rather, they were given standard learning set exposure (no levers present) and then were presented with more pronounced changes in the lever position. All 3

monkeys were presented with lever position Forward 1. Upon reaching the criterion (which was the same as in Experiment 1) with that lever position, 2 monkeys were presented with the position Widest (Hank and Han), and the 3rd monkey (Chewie) was presented with position Wider before position Widest. Han and Chewie met criterion at position Widest, and then they were presented with position Lower. Here, only Han succeeded, and then he was presented with positions Lowest and Random. He met criterion for both of those positions, and thus finished the sequence. After 60 blocks of 120-trials, not only had Chewie failed to reach criterion on position Lower, he also failed to exceed chance levels of responding. After 35 blocks of 120-trials, Hank failed to reach criterion on position Widest, and he also failed to exceed chance levels of responding. Hank was returned to the standard learning set condition (no lever present). Upon reaching criterion at that condition, he was presented with lever positions Forward 1, Forward 2, Widest, Lowest, and Random, and this time he met criterion on all of these positions. Thus, his second attempt involved the addition of one more step in which the levers were close to the stimuli before being moved farther away from the stimuli.

Results

Again, there was great variability in the number of 120-trial blocks needed to reach criterion as a function of lever position (Figure 4). Han was the most successful of these three monkeys when presented with a more rapid sequence of moving the levers away from the stimuli. Han was significantly better than chance (for Trials 2 through 6) on the first 120-trial block for positions Forward 1, Lower, and Random, all $\chi^2(1, N = 100) > 21.00, p < .01$, and he met criterion with all lever positions that were presented to him. Chewie was significantly better than chance (for Trials 2 through 6) on the first 120-trial block for positions Forward 1 and Wider, both $\chi^2(1, N = 100) > 6.75, p < .01$, but he did not progress through the

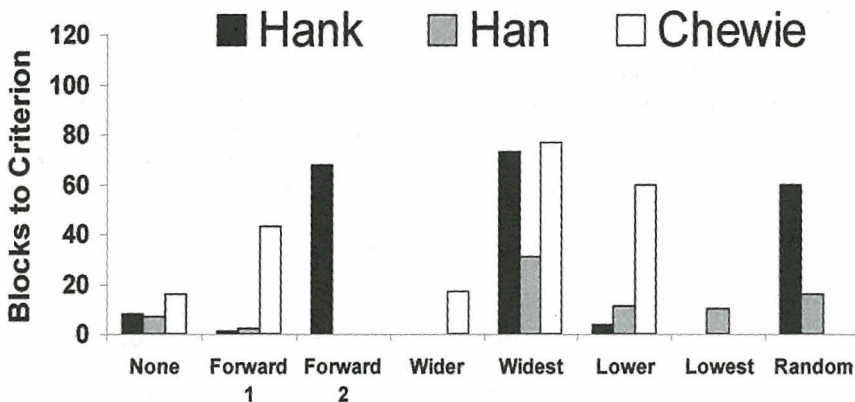


Figure 4. Number of 120-trial blocks to reach criterion at each lever position for each monkey. Note that each animal was given a difference sequence of lever positions, resulting in some missing bars in the figure.

entire sequence. As noted, after initially failing to meet criterion with any lever position beyond Forward 1, Hank was presented with one additional progression of the levers away from the stimuli early in the sequence (position Forward 2). On the second attempt, Hank was significantly better than chance (for trials 2 through 6) on the first 120-trial block for all positions, all $\chi^2(1, N = 100) > 6.76, p < .01$, except the position Forward 2, $\chi^2(1, N = 100) = 1.96, p > .05$, and he met criterion for all lever positions for this second progression.

Discussion

The performances of these 3 monkeys were mixed. One animal, Han, demonstrated that the number of steps required to move the levers away from the stimuli could be greatly reduced from that reported in Experiment 1. Another animal, Chewie, performed well with many of these more abrupt shifts in the lever positions, but he had great difficulty when he had to move the cursor to the lowest regions of the monitor (farthest away from the stimuli). In the first attempt with Hank, the increase in spatial separation between cue stimuli and lever position Forward 1 to lever position Widest had a detrimental effect on performance. Hank not only failed to reach criterion, he also failed to exceed chance levels of responding, and he failed to show any increase in performance across time. With the introduction of just one more progressive movement of the levers from the cue stimuli, however, Hank's performance began to look like that of Baker, Willie, and Han. Hank was significantly better than chance at the outset of all but one of the new lever positions during this second progression. Thus, more immediate separation of cue and response loci than in Experiment 1 did not appear to eliminate learning set in these rhesus monkeys, although it did have some effect on how far all of the animals could progress in the sequence.

In comparison to Hank, Chewie and Han had very little experience using a joystick and responding to computer-generated stimuli (a conservative estimate of this difference would be that Hank had 100 times more experience). Yet, these 2 monkeys were equivalent to Hank and the highly experienced monkeys from Experiment 1 in their ultimate performance on this task. In fact, Han was the best performing monkey in Experiment 2. This indicates that extensive experience with joysticks and computerized tasks is not necessary for monkeys to overcome second-order S-R discontinuity in the context of joystick responding to computer stimuli.

General Discussion

When responding manually to presented stimuli using an apparatus like the WGTA, rhesus monkeys have great difficulty in correctly selecting response loci spatially removed from the stimuli to be discriminated. Even with gradual increases in spatial discontinuity between response loci and stimuli, monkeys sometimes fail completely in discriminations which are otherwise very easily learned. And yet, when stimuli are presented on a

computer screen, and are nowhere near the actual response locations at which the monkeys move their wrists and flex their fingers, they perform at levels comparable to, or even better than, when they use a manual apparatus requiring them to touch stimuli. What can account for this performance? Is it simply that the cursor comes to act as a surrogate "finger" for the animal (Shuck, 1960), in the sense that visual fixation on the cursor serves to transfer attention to the cursor to such a degree that the spatial discontinuity of hand and cursor is qualitatively different to the animal from the discontinuity of response loci and stimuli in the WGTA? If so, spatial discontinuity within the computerized tasks in which cursors act as pointing devices should produce comparable deficits to those seen in the use of manual apparatus. In both cases, the orienting response of the monkeys should be toward the response sites, and not the stimuli, and thus no learning of the correct stimulus would occur because stimulus sampling occurs only during an orienting response prior to the instrumental response (Polidora & Fletcher, 1964). The data from the present task offer some indication that this is not true. All 5 animals successfully responded to stimuli separated in space from their hands through responses to other locations on the computer screen also spatially removed from the stimuli (second-order S-R spatial discontinuity). One animal did so at a high level even without the gradual dissociation of stimuli and response loci, and 2 others showed fairly high performance for some lever positions even though 1 of those 2 did not make the immediate leap from spatial contiguity to extreme spatial discontinuity and had to be given one more step in the progression. Thus, second order S-R spatial discontinuity did present some problems if presented in too extreme a progression, but it was otherwise overcome by all monkeys, and for the majority of the monkeys this included making responses to lever positions as far away from the stimuli as possible on the monitor.

Polidora and Thompson (1965) suggested another way in which spatial discontinuity could be overcome by monkeys, and it involved double responses in which animals first touched stimuli and then touched response loci. In that case, monkeys had to orient to both the stimuli and the response loci, thus allowing for the stimulus sampling necessary for learning to occur. In the case of our monkeys, there was no possibility of them physically to touch either the stimuli or response loci, but there was the opportunity to move the cursor toward the stimuli before moving toward the response loci. Given the progression of locations, we could not discern whether this might be occurring for positions in which the levers were along the same line of sight as the stimuli. However, when levers and stimuli were accessible to the cursor only through different motor responses, we saw little evidence that the animals first moved to the stimuli and then to the levers. Therefore, the monkeys were not making double responses during the task.

With the presentation of the levers, performance dropped for all animals, and it did so again on some (but not all) occasions when levers were moved to new positions. Although each new lever position required a new

motor pattern to make a response, some could be thought of as very minor changes, such as from position Small to Smaller, whereas others were very substantial (e.g., Widest to Lower or Lower to Lowest). However, for many progressions to new lever positions, the monkeys responded above chance levels from the very first block of trials. Thus, the levers were being used appropriately across their various positions, indicating that the monkeys did not have to relearn how to use them. Rather, they had to reestablish performance levels indicative of their perceptual and cognitive capacities for making the trial discriminations by correctly executing the motor responses needed to contact the levers associated with the stimuli. One might have expected that each new lever position would have produced less disruption of the high levels of responding seen at the end of testing on the previous lever position (i.e., a learning set for the use of the lever), but this was not true. Rather, the animals were somewhat idiosyncratic with regard to which lever positions produced the greatest levels of disruption, and no consistent pattern of progressively better performance from the outset for subsequent positions emerged.

Why computerized tasks allow for this high level of performance compared to manual apparatus use remains unclear. It is possible that the visually clear field of the monitor's screen might be a facilitator of learning and performance. Although the typical WGTA tray does not appear to be visually noisy, perhaps it is to the monkey. Given the isomorphic relationship between movement of the joystick and observed movement of the cursor on the clear-channel screen, the monkey learns all that it ever needs to know about control in the situation. Because the levers initially are near the discriminanda, the monkeys rapidly learn the functional value of those levers. From that point, relocation of the levers is only slightly distracting, though the effect might change rapidly if the visual field on the screen were made noisy. Perhaps it is the use of a joystick that results in such competencies. We are beginning to train other experimentally naive monkeys employing touchscreen technology rather than joysticks to determine whether it is the computerized format of trial presentations or the response input modality that leads to this highly successful learning set performance with S-R spatial discontinuity. Whatever the eventual answer, it is not the case that computerized tasks simply result in animals responding with a cursor as if the cursor were a fingertip, suggesting that some other perceptual or cognitive mechanism reacts more appropriately within the context of computerized tasks.

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