Element discriminability as a determinant of serial-pattern learning

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Hulse and Dorsky found that rats were better able to track (run slowly to) 0 food pellets in a strongly monotonic (decreasing) serial pattern (14-7-3-1-0 food pellets) than in either a weakly monotonic one (14-5-5-1-0) or a nonmonotonic one (14-1-3-7-0). These findings were seen as incompatible with associative approaches based on animal experiments. Instead, they were taken to be consistent with cognitive theories of human behavior that relate pattern difficulty to formally defined structural complexity. In Experiment 1, tracking was found to be poorer with a strongly monotonic series (15-10-5-0) than with either of two weakly monotonic series (15-15-0-0 or 14-14-2-0), and in Experiment 2 a nonmonotonic series (1-29-0) produced better tracking than a strongly monotonic one (20-10-0). Although these results are not necessarily incompatible with the structural complexity view, they do suggest that "element discriminability" is a factor in serial-pattern learning. They are, therefore, compatible with a memory approach that views tracking as a form of discrimination learning.

The issue of how best to characterize what is learned is a recurring one. Recently the issue was raised by Hulse and Dorsky (1977), who stressed the importance of serial-order learning, how animals learn relationships among events. Hulse and Dorsky suggested that while cognitive views of serial-order behavior have been extremely fruitful, particularly those based on artificial intelligence and human pattern learning, associative stimulus-response views based on animal data have been sterile since at least the 1930s. Hulse and Dorsky suggested that serial-pattern learning is determined by the structural complexity of patterns and that cognitive theories provide useful formal rules for distinguishing pattern structures with regard to complexity. For example, monotonic series are seen as less complex than nonmonotonic series.

Hulse and Dorsky employed what appears to be a most promising procedure to investigate serial-order learning. In the first of their two experiments, rats were given successive trials in a runway either to 14-7-3-1-0 pellets, a strongly monotonic series, or to 14-1-3-7-0 pellets, a nonmonotonic series. Experiment 2 compared the 14-7-3-1-0 strongly monotonic series to a 14-5-5-1-0 weakly monotonic series. The reward magnitudes employed were referred to as "elements" of the series. Concern was with slow running to the 0-pellet element, called "tracking." Tracking was better, i.e., running was slower to 0 pellets, in the strongly monotonic series than in either the nonmonotonic or the weakly monotonic series. These general findings were seen as relevant

to the issue of what animals and people learn. On the one hand, it was suggested that rats, like people, construct internal representations of the structure of patterns, and thus learn the simpler monotonic series more easily than the more complex nonmonotonic series. On the other hand, Hulse and Dorsky suggested that their findings cannot be explained by any theory which emphasizes reinforcement contrast, associative chaining, frustration or excitation, and inhibition, which encompasses, it would seem, almost all available animal learning theories.

The sequential view (e.g., Capaldi, 1967, 1979) has also emphasized the importance of serial-pattern learning, which it conceptualizes as a form of discrimination learning. In the patterning case, discrimination learning is based on the differential reinforcement of cues produced by reward events (memories) rather than, as in more conventional cases of discrimination learning, brightness cues or form cues, and so on. According to the present view, each distinctive reward magnitude or element of the series gives rise to a distinctive memory. This memory is retrieved on the next trial, where its capacity to elicit or inhibit the reaction is determined by the reward occurring on that trial. In the Hulse and Dorsky studies, the memory which occurred on 0-pellet trials was an S- cue, with certain other memories which occurred on rewarded trials being S+ cues.

Pattern learning depends on what might be called "element discriminability." That is, if the S+ and S- elements are similar, pattern learning will be poorer than if the S+ and S- elements are dissimilar. Memories are assumed to be arrayed along a stimulus continuum, the memory of large re-

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ward on the left that of nonreward on the right, with memories of intermediate reward magnitudes having intermediate positions (see, e.g., Capaldi, 1967). Thus, the memory of nonreward or 0-pellet reward, S^0 , is more similar to the memory of 1-pellet reward, S^1 , than it is to the memory of 2-pellets reward, S^2 , and so on.¹ The purpose of the two investigations reported here was to render the memory approach to serial-pattern learning more plausible by showing that, under some conditions at least, element discriminability may be a more important factor than structural complexity in determining tracking.

EXPERIMENT 1

In Experiment 1 of the Hulse and Dorsky report, all elements contained in the strongly monotonic series (14-7-3-1-0) were also contained in the non-monotonic series (14-1-3-7-0). Where this is so, according to the memory view, it is perhaps likely that better tracking will result from a monotonic arrangement of the elements than from a nonmonotonic one, a point which will become clearer in the general discussion section. However, in Experiment 2 of the Hulse and Dorsky report, only some of the elements contained in the strongly monotonic series (14-7-3-1-0) were also contained in the weakly monotonic series (14-5-5-1-0). According to the memory view, where two series share few or no elements in common, it depends entirely on the particular elements selected whether the best tracking will result from an arrangement that is strongly monotonic, weakly monotonic, or nonmonotonic. Accordingly, an attempt was made in Experiment 1 to select elements such that element discriminability would be least and thus tracking would be poorest in a strongly monotonic series (15-10-5-0) than in either of two weakly monotonic series (15-15-0-0 and 14-14-2-0). Each of the groups in Experiment 1 received 30 pellets over the four trials of the day, and so here, as in the Hulse and Dorsky investigation, all groups received the same number of pellets over the trials of the day.

Method

Subjects. The subjects were 21 male albino rats, 115 days old at the start of the study, purchased when about 90 days old from the Holtzman Co., Madison, Wisconsin.

Apparatus. The apparatus was a runway, 202.3 cm long, 11.1 cm wide, and 22.9 cm high, painted flat gray. The initial 19.1 cm of the runway, separated by a guillotine-type door, served as a startbox. Operation of the start door initiated the first of three clocks (.01 sec). Clock 1 was stopped (start time) and Clock 2 started when the rat interrupted a photobeam 6.35 cm from the start door. Clock 2 was stopped (run time) and Clock 3 started when the rat interrupted a second photobeam 132.1 cm from the first. Clock 3 was stopped (goal time) when the rat interrupted a third photobeam 33.4 cm from the second. The last

29.8 cm of the runway served as a goalbox in which the rat could be confined by the lowering of a guillotine-type door. The goalbox contained a brass cup which was removable. The entire apparatus was covered by wire mesh on a hinged frame.

Pretraining. Upon arrival at the laboratory, rats were housed individually and given unlimited access to both food and water. On Day 1 of pretraining, the rats were handled for approximately 3 min each and placed on a food-deprivation schedule on which they were maintained for the remainder of the experiment at 12 g/day Wayne Lab Blox. Water remained available in the home cage at all times. Handling times decreased for each rat over successive pretraining days.

Pellet training took place on Days 8-9 of pretraining. In the home cage, the rats were given 15 .045-g Noyes pellets in a glass coaster. Food rations were adjusted accordingly to maintain the deprivation level at 12 g/day. On Day 10, each subject was given one rewarded trial (15 pellets) in the alley with all clocks operational, but latencies were not recorded. Rats were then randomly divided into three groups of seven each designated 15-10-5-0, 15-15-0-0, and 14-14-2-0, corresponding to the reward magnitudes received on each trial during acquisition.

Experimental training. Rats received 4 trials/day for 12 days of training. They were run in squads of three animals, one from each group. Squads were run in the same order each day; however, running order within a squad was randomized every day. Trials were administered such that no rat received its second trial before all others had received the first trial, resulting in an intertrial interval of approximately 4 min.

To begin a trial, the rat was removed from a holding cage and placed in the startbox. Approximately 3 sec later, the start door was raised regardless of the rat's orientation and the first clock started. The rat was given 60 sec to traverse each alley section for a total time of 180 sec. If a rat did not succeed in traversing an alley section in the allotted 60 sec, a score of 60 sec was assigned to that alley section and the remaining time was added to the time recorded for the next alley section. If the total allotted time of 180 sec elapsed without the rat reaching the goal, the rat was removed from the alley and placed in the enclosed goalbox.

The rat was removed from the goalbox after all of the pellets had been consumed. On nonrewarded trials, the rat was confined in the goalbox for 30 sec. All rats spent the intertrial interval in a holding cage in which water was always freely available. Rats were fed their adjusted rations in the home cage approximately 15-20 min after the final trial of the day.

Results

Hulse and Dorsky reported time over the total length of the runway. By the final days of training in Experiment 1, it became clear that all groups had learned to track the 0-pellet element, with tracking being substantially better toward the goal section of the runway and in the weakly monotonic groups. This may be seen in Figure 1, which shows running speed on each of the four trials of the last 2-day block of training trials in each of the alley sections, start, run, and goal. The trends apparent in Figure 1 are supported by statistical analyses in which the rejection region was set at $p < .05$. An analysis of the data shown in Figure 1 indicated that no difference was significant in the start section. In the run section, while the groups did not differ significantly, the interaction of groups with elements was significant [$F(6,54) = 2.30, p < .05$], indicating that the three groups performed differently over the four

Figure 1. Running speed (1/sec) for each of the groups on the four trials of the last 2-day block of trials in each of the alley sections, start, run, and goal.

trials of the day. In the goal section, the groups differed significantly [$F(2,18) = 5.06, p < .05$], and the interaction of groups with elements was significant as well [$F(6,54) = 2.58, p < .05$]. Subsequent Newman-Keuls tests indicated that in the run and goal sections the two nonmonotonic groups ran more slowly ($p < .05$) than the monotonic group on 0-pellet trials, with no other difference between the groups being significant.

Turning to within-groups comparisons, Newman-Keuls tests also indicated that each of the groups had learned to track the 0-pellet element, inasmuch as in the run and goal sections each group ran reliably more slowly ($p < .05$) on 0-pellet trials than on any other, with no other difference being significant. The differences shown in Figure 1 developed over the course of training. Consistent with this comment is the fact that statistical analysis revealed that over the first 2-day block of trials no difference approached significance. Moreover, tracking appeared earlier in the two weakly monotonic groups than in the monotonic group. The first reliable differentiation of the last element in the series occurred on Day 6 of ac-

quisition training. On Day 6, the interaction of groups with elements was significant in the run section [$F(6,54) = 2.46, p < .05$] and in the goal section [$F(6,54) = 2.73, p < .05$]; and subsequent Newman-Keuls tests indicated that in these sections running was reliably slower on 0-pellet trials than on the remaining trials in the two weakly monotonic groups but not in the monotonic group.

Discussion

In Experiment 1, Group 15-15-0-0 did not track the third element. This was because S^{15} was retrieved on Trial 2, a rewarded trial, as well as on Trial 3, a nonrewarded trial, and so S^{15} was a partially rewarded $S+$ cue. On Trial 4, where tracking occurred, S^0 was retrieved; S^0 was retrieved only on the nonrewarded Trial 4, and so S^0 was a consistently rewarded $S-$ cue which produced tracking.

EXPERIMENT 2

The results obtained in Experiment 1 were not consistent with the structural complexity view, inasmuch as a strongly monotonic series produced poorer tracking than either of two weakly monotonic series. Experiment 2 compared a strongly monotonic series (20-10-0) to a nonmonotonic one (1-29-0). The element discriminability view expected tracking to be better under the 1-29-0 nonmonotonic series than under the structurally simpler 20-10-0 monotonic series.

Method

Subjects. Twenty rats, about 120 days old, of the same description as those employed in Experiment 1 were subjects.

Apparatus. The apparatus was the same as that employed in Experiment 1.

Procedure. All aspects of the procedure employed in Experiment 2 were, except where specifically noted, identical to those employed in Experiment 1. The rats were divided into two groups of 10 each, designated 1-29-0 and 20-10-0, corresponding to the reward magnitude received on each trial. Pellet training occurred on Days 9-10, all rats receiving 10 .045-g Noyes pellets in the home cage. Acquisition training began on Day 11 and continued for 22 days. The squads were composed of four rats, two from each group.

Results

The tendency for tracking to improve as the goal section was approached was also evident in Experiment 2, but was not nearly so marked as in Experiment 1. Essentially the same general findings were obtained in each of the three alley sections. In the interest of simplicity, only speeds along the total length of the alley are reported, these being quite representative of those obtained in each of the three alley sections. Figure 2 shows total speed for each of the two groups on each of the three trials of the last 2-day block of training trials. Figure 2 shows that both groups were able to track the 0-pellet element

Figure 2. Running speed (1/sec) for each of the groups along the total length of the runway on the last 2-day block of trials.

but that such tracking was better under the 1-29-0 nonmonotonic pattern than under the 20-10-0 monotonic pattern. Another major difference between the groups was that whereas Group 20-10-0 tended to track only the 0-pellet element, Group 1-29-0 tracked not only the 0-pellet element but the 1-pellet element as well.

An analysis of the data shown in Figure 2 indicated that the groups differed significantly [$F(1,18) = 50.34, p < .01$] and that the interaction of elements and groups was significant as well [$F(2,36) = 11.05, p < .01$]. Subsequent Newman-Keuls tests indicated that tracking of the 0-pellet element was better in the nonmonotonic group than in the monotonic group ($p < .05$). In addition, the two groups differed on the first trial of the day ($p < .01$) but not on the second.

Turning to within-groups comparisons, Newman-Keuls tests indicated that the only difference which was not significant ($ps < .01$) in Group 20-10-0 was that between the 20- and 10-pellet trials, while the difference which was not significant ($ps < .01$) in Group 1-29-0 was that between the 1- and 0-pellet trials. The differences shown in Figure 2 developed over the course of training, as statistical analysis revealed that over the first 2-day block of training trials no difference even approached significance. Also, tracking appeared earlier in Group 1-29-0 than in Group 20-10-0. The first reliable differentiation of the last element in the series occurred on Day 15 of acquisition training. On Day 15, the interaction of groups with elements was significant [$F(2,36) = 6.28, p < .01$]; and subsequent Newman-Keuls tests indicated that while Group 20-10-0 ran equally rapidly on all trials, Group 1-29-0 ran more slowly on 1-pellet and 0-pellet trials than on 29-pellet trials.

Discussion

In Experiment 2, Group 1-29-0 not only failed to run faster than Group 20-10-0 on Trial 2 of the day but actually ran somewhat more slowly. Although this difference was not significant, it deserves comment inasmuch as it seems paradoxical that somewhat slower running was associated with the larger reward magnitude. Theories that stress inhibition, as does the present one, could account for this as follows. In Group 20-10-0, only 0-pellet trials were inhibitory, whereas in Group 1-29-0, 1-pellet as well as 0-pellet trials were inhibitory. Thus, greater inhibition may have been associated with a variety of cues, including apparatus cues, in Group 1-29-0 than in Group 20-10-0, reducing running speed in Group 1-29-0.

GENERAL DISCUSSION

The element discriminability view will be applied initially to the findings obtained in Experiment 2. In the series 1-29-0, the memory S^1 was retrieved on 29-pellet trials while the memory S^{29} was retrieved on 0-pellet trials. Thus, in the series 1-29-0, S^1 was an S+ cue and S^{29} an S- cue. In the series 20-10-0, the memory S^{20} retrieved on 10-pellet trials was the S+ cue and the memory S^{10} retrieved on 0-pellet trials the S- cue. Inhibition is acquired directly by the S- cues on 0-pellet trials. And in patterning, as in any discrimination learning problem, responding to the S- cue depends upon directly acquired inhibition and generalized habit from rewarded memories or the S+ cues; hence, the importance of element discriminability. Thus, in Experiment 2, the greater the similarity between the S+ and S- cues, the less the tendency toward tracking, S^{20} and S^{10} (20-10-0 series) being more similar than S^1 and S^{29} (1-29-0 series).

Consider now Experiment 1. In the series 15-10-5-0, there were two rewarded memories or S+ cues, S^{15} and S^{10} , the S- cue being S^5 . In the series 14-14-20-0, there was only one S+ cue, S^{14} , the S- cue being S^2 . And in the series 15-15-0-0, S^{15} was the S+ cue, S^0 the S- cue. Thus, in Experiment 1, the greater the similarity between the S+ and S- cues, the less tendency toward tracking, S^{10} and S^5 (15-10-5-0 series) being more similar than S^{14} and S^2 (14-14-2-0 series), which in turn are more similar than S^{15} and S^0 (15-15-0-0 series). Of course, tracking in the 15-15-0-0 series was only absolutely and not significantly better than in the 14-14-2-0 series. This may indicate that, to the rat, the cues S^{15} and S^0 are not much more dissimilar than the cues S^{14} and S^2 .

The series employed by Hulse and Dorsky, like the 15-10-5-0 series employed in Experiment 1, contained more than one S+ cue. For each of those series, let us identify the S- cue and the S+ cue most similar to it. In the 14-7-3-1-0 series, the S- cue was S^1 , the most similar S+ cue being S^3 . The

corresponding cues for the 14-1-3-7-0 series were S^7 and S^3 . And for the series 14-5-5-1-0, they were S^1 and S^5 . On this basis, element discriminability appears to have been low in the series that produced the best tracking, S^3 and S^1 (14-7-3-1-0 series) being more similar than S^5 and S^1 (14-5-5-1-0 series), and perhaps not much more or less dissimilar than S^3 and S^7 (14-1-3-7-0 series). Thus, while the structural complexity view has some difficulty in dealing with the findings obtained here, the element discriminability view has some difficulty in dealing with the findings obtained by Hulse and Dorsky. This is not to say that alternatives are not open to the element discriminability view in relation to the Hulse and Dorsky findings. However, in the absence of further information, speculations along this line may be regarded as ad hoc, particularly in view of the possibility that both element discriminability and structural complexity may be involved in tracking, which is, after all, a complex instrumental behavior. Given the proper conditions, either factor may dominate the other. With this in mind, let us examine differences in the experimental conditions employed here and by Hulse and Dorsky.

The present investigation employed four-element series (Experiment 1) and three-element series (Experiment 2), whereas Hulse and Dorsky employed five-element series. In our experiments, a given series was run once each day, while Hulse and Dorsky used several repetitions of their series each day with an interseries interval of about 15-min. Another pos-

sibly major difference was that the time between the successive trials of a series was about 4 min here and only 10 to 15 sec in Hulse and Dorsky. Any of the procedures employed by Hulse and Dorsky may have been favorable to the dominance of structural complexity over element discriminability. For example, when the time between the successive trials of a series is very short, as it was in Hulse and Dorsky, it may be easier to react to the series as a whole and hence its structure, thereby reducing the importance of the element discriminability factor. On the other hand, further research may reveal that a single interpretation is capable of dealing with all serial learning data.

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NOTE

1. Usually the memory of 0-pellet reward is represented as S^N . Here S^0 seems preferable.

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