SEQUENTIAL EFFECTS IN DIMENSIONAL CONTRAST

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Two experiments examined pigeons' response rates during short trials signaled by stimuli closely spaced along a wavelength continuum. In Experiment 1 separate halves of the continuum were correlated with different reinforcement schedules. In Experiment 2, the middle stimulus was accompanied by a lower probability of reinforcement than were the remaining wavelengths. Both procedures resulted in dimensional contrast "shoulders," seen as relatively enhanced or depressed response rates in the presence of stimuli between the extreme of the continuum and the border separating the positive and negative stimuli. Sequential analyses addressed possible contributions of the following interactions: (a) local contrast, seen when rate during a given schedule depends on the schedule in the just-preceding trial; (b) modification of local contrast by the similarity of the signaling stimuli (P. Blough, 1983); and (c) schedule-independent rate contrast, seen when rate in a given trial depends on the rate controlled by the stimulus that accompanied the just-preceding trial (Malone & Rowe, 1981). Dimensional contrast functions were similar when isolated according to the schedule, to the similarity of the signaling stimulus, and to the response rate of the just-preceding trial. The interactions noted above do not appear to make important contributions to this effect.

Key words: dimensional contrast, local contrast, stimulus similarity, rate contrast, key peck, pigeons

When pigeons perform on multiple schedules, responding during a constant component depends on the alternative stimulus and schedule values present in the session. This paper addresses one such contextual effect, "dimensional contrast" (D. Blough, 1975). In dimensional contrast, composition of the stimulus set appears to modify response rate during a constant reinforcement schedule.

Figure 1 illustrates this phenomenon. Some of these data come from the experiments to be described in the following pages. In these and related studies, most stimuli were presented equally often and in a quasirandom order during a session. The top panel of Figure 1 describes the outcome of an experiment in which one half of the stimulus continuum [S(lean)] was correlated with a relatively low

probability of reinforcement and the other half [S(rich)], with a relatively high such probability. Dimensional contrast is seen in the negative and positive "shoulders," appearing respectively in the left and right sides of the function. In the negative shoulder, rate in the middle of the S(lean) continuum is relatively depressed; in the positive shoulder, rate in the mid-portion of the S(rich) region is relatively enhanced. The bottom half of Figure 1 illustrates another form of dimensional contrast. The data come from an experiment (D. Blough, 1975) that used a single S-, positioned in the middle of a continuum, while its neighbors on either side all were accompanied by equivalent, higher reinforcement probabilities. Positive shoulders on either side of the S- define the dimensional contrast effect.

Portions of these contrast shoulders reflect generalization decrements; that is, it is not surprising that response rate changes gradually as the stimuli become less like those associated with the alternative schedule. Thus, in Figure 1, generalization decrements can account for the portions of the shoulders that

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Fig. 1. Two examples of dimensional contrast. The top panel displays data from the present experiment. Stimuli to the left of the dashed line accompanied a low reinforcement probability and those to the right, a higher such probability. Dimensional contrast is seen in the rate reversal at the extremes of the continuum. The bottom panel shows data from D. Blough (1975). The dashed line indicates the single S^- , and the contrast shoulders appear both to its left and its right.

neighbor the border separating the two schedules. However, it is less easy to explain the reversal in rate that occurs when the stimuli approach the extremes of the continuum. This reversal completes the shoulder that defines dimensional contrast.

One account of this phenomenon (D. Blough, 1975, 1983) is related to Wagner and Rescorla's (1972) model of classical conditioning. Blough's model draws from Wagner and Rescorla the rule that changes in associative strength are proportional to the difference between current and asymptotic strength. Thus, according to Wagner and Rescorla, a reinforced trial with a given stimulus will produce a relatively large change if current associative strength for that stimulus is far below its asymptotic strength. In his modification of that model, Blough added generalization factors that permit associative strengths of stimuli along a continuum to interact with the associ-

ative strengths of their neighbors. The resulting formulation accounts rather well for functions like that in the bottom panel of Figure 1. Of special importance are the S^+ wavelengths that border the single S^- . Because these stimuli share elements with the S^- , large discrepancies persist between their current strength and their potential asymptotic strengths. Positive contrast shoulders occur because these border stimuli also share elements with their S^+ neighbors to the other side. Reinforced presentations of a border stimulus generate large strength increments that generalize to its immediate neighbors, pushing up the rates occasioned by these adjacent stimuli. Although Blough's model successfully predicts the shoulders, it sometimes fails to account for their size (D. Blough, 1975, 1983; Rowe & Malone, 1981).

It is possible that other processes contribute to dimensional contrast. For example, sequential interactions among components may be important (Malone & Rowe, 1981; Rowe & Malone, 1981). One such interaction is local contrast, seen when rate during a constant schedule component depends on the schedule prevailing during the preceding component. When the preceding component entails a richer schedule, rate in the constant component is relatively depressed. Analogously, when the preceding component is relatively lean, rate in the constant component is enhanced. Of special importance is the fact that local contrast is greater when successive components are not too well discriminated (e.g., P. Blough, 1983; Nevin & Shettleworth, 1966); thus, local contrast may contribute to dimensional contrast because stimuli identified with the shoulders are more likely to have been part of moderately similar S^-/S^+ sequences. For example, in the bottom panel of Figure 1, the peaks occur at S^+ values fairly close to the S^- . In a different dimensional-contrast paradigm, Malone and Rowe reported that, early in training, dimensional contrast is stronger in functions that isolate S^-/S^+ sequences; that is, conditions that favor local contrast also favor dimensional contrast.

Malone and Rowe (1981) have described a second sequential effect that includes inter-

actions among components that involve different response rates. Positive rate contrast occurs when a component signaled by a stimulus associated with a relatively low rate leads to an enhanced rate in the following component; analogously, in negative rate contrast, a stimulus associated with a high average rate will lead to a depressed rate in the following component. With extended discrimination training, rate interactions may amplify dimensional contrast because response rates near the S+/S- border, initially depressed (or enhanced) through local contrast, push the rates of their neighbors in the opposite direction. For example (Figure 1, bottom panel), because stimuli in the shoulders have become associated with relatively high rates, rates in components that immediately follow those stimuli would be depressed. Rate contrast can thus occur in the absence of schedule differences between the interacting components. In their analysis, Malone and Rowe showed that, late in training, dimensional contrast was no longer attributable to schedule sequences alone.

D. Blough's model does not incorporate local schedules and rate interactions; if such effects are important, they may help account for the model's failures to predict shoulder size. The present experiments examined sequential effects in two dimensional-contrast paradigms. Experiment 1 employed a procedure designed to yield both positive and negative shoulders. Experiment 2 reanalyzed D. Blough's (1975) data for sequential effects. In both studies, perceptually scaled stimuli facilitated the analysis of similarity effects. We evaluated the role of local interactions by comparing dimensional-contrast functions isolated according to certain classes of component sequences.

EXPERIMENT 1

METHOD

Subjects. Six adult male White Carneaux pigeons served. Four had participated extensively in procedures that used multiple schedules. Of these, Birds 640, 671, and 878 had learned a discrimination between 567 (S-) and 600 (S+) nm. Birds 546 and 704 had learned a dis-

crimination between 625 (S-) and 600 (S+) nm. Bird 244 was experimentally naive. The birds' running weights were approximately 80% of their ad-lib weights, modified for each bird on the basis of its performance. After initial training, sessions were not run on days when the bird's running weight departed by 20 or more grams from the established running value.

Apparatus. Subject chambers were three Lehigh Valley Electronics pigeon boxes, housed in a room separated from optical and controlling equipment. Ventilating fans and speakers delivering white noise helped further mask extraneous sounds. The front panel of each chamber contained a 2.5-cm response key located centrally and 25 cm above the floor. Operation of the key required a force of approximately 0.1 N. A small tungsten projector, mounted behind the panel, provided a 1-cm horizontal line on the top portion of the key. Below the key, 12 cm above the floor, was a 5- by 6-cm opening for access to a food tray mounted behind the panel. A shielded 6-V lamp provided indirect houselight illumination.

A Bausch and Lomb 250-mm grating monochromator controlled stimulus wavelength. Its source was a General Electric T10 6-V tungsten lamp, operated at 16 A. The entrance and exit slits of the monochromator were set to provide a nominal half-band width of 17 nm. Monochromatic lights passed through a balancing wedge and a series of lenses that focused an image of the monochromator's grating first on a neutral density wedge and later on ends of three 3-mm fiber optic cables. The far ends of the cables were positioned just behind the response keys. Shutters mounted at the entrance to the cable system permitted independent control of key illumination in the three boxes. Luminance at the keys was approximately 6.2 cd/m²; values at all wavelengths were equated for the pigeon's spectral sensitivity (D. Blough, 1957).

A Digital Equipment Corporation PDP 11-03 computer provided on-line control of all experimental events. Interfacing equipment included stepping motors that operated the monochromator and the neutral density

wedge. The computer also sensed and recorded responses and performed most data analyses.

Procedure. Experimental sessions consisted of a series of trials separated by 5-s intertrial intervals (ITIs). At the start of a trial the houselight came on and the monochromatic stimulus appeared. During the following 20 s responses were recorded but had no programmed consequences. Following this period a 5-s hold began; the first response during the hold turned off the monochromatic stimulus, illuminated the line at the top of the key, and, with a stated probability, operated the food magazine. The line was present while food was available; when food reinforcement was not scheduled, the line presentation lasted 1 s. Following reinforcement or the termination of the hold period, whichever came first, the houselight went out and the ITI began.

There were 16 stimulus wavelengths, centered around 600 nm and separated by equally discriminable steps (Wright, 1978). Final experimental sessions included 257 stimulus presentations. A session included an initial trial and all 256 possible stimulus sequences; the order of these sequences varied from day to day.

There were two groups of 3 subjects each; the groups differed in the range of the stimulus continuum and the contingencies that accompanied its two halves. Table 1 lists the wavelengths employed. For Group H (Birds 640, 671, 878), a steady horizontal line signaled reinforcement for responses to Stimuli 9 to 16; a flickering line signaled reinforcement for Stimuli 1 to 8. For Group L (Birds 244, 704, 546), these correlations were reversed.

The experienced birds began on the trial-wise procedure at the start of a training period. Bird 244 first learned to peck at monochromatic lights of several wavelengths through an autoshaping procedure. For all subjects, the hold period initially had a duration of 10 s; it was reduced to 5 s when responding appeared stable. Probability of food reinforcement decreased and total trials increased gradually during initial sessions. Magazine time also varied during training sessions, but had a value of 3 s for all birds during the experiment proper.

Table 1
Stimulus Wavelengths (nm) for Each Group

<i>Stimulus</i>	<i>Group H</i>	<i>Group L</i>
1	575	561
2	580	568
3	584	575
4	588	581
5	591	586
6	594	591
7	596	594
8	598	597
9	600	600
10	602	603
11	605	606
12	607	609
13	609	612
14	611	615
15	614	620
16	616	624

The experiment proper consisted of two phases. During the initial baseline phase, all stimuli were correlated with equal probabilities of food reinforcement (.25). Baseline sessions continued until the bird met a stability criterion for trend (Speelman & Gollub, 1974). This criterion, applied to overall rates in both halves of the continuum, required a minimum of 15 sessions including a final series of 9 sessions in which rates did not change consistently in one direction. One additional session followed the completion of the criterion series, so that final baseline period ended after 10 stable sessions. For Group L, training lasted 16, 22, and 19 sessions for Bird 244, 704, and 546, respectively; training for Group H lasted for 20, 16, and 27 sessions for Birds 640, 671, and 868, respectively.

During the testing phase that followed, different probabilities of food reinforcement applied to each half of the continuum. For Group H, the upper half [S(rich)] accompanied a probability of .33 and the lower half [S(lean)], a probability of .08. For Group L, the upper half [S(lean)] accompanied a probability of .10 and the lower half [S(rich)], a probability of .33. Testing lasted for 15 sessions.

RESULTS AND DISCUSSION

By the end of the baseline phase, all birds responded at approximately equal rates in the presence of all stimuli. Discrimination between the two halves of the continuum devel-

Fig. 2. The course of dimensional contrast over the first 15 test days, grouped in blocks of 3. See Table 1 for the wavelengths corresponding to stimuli numbered on the abscissa. The left column shows data for Group H, for which reinforcement probability was higher in components signaled by Stimuli 9 to 16. The right column shows data for Group L, for which stimulus-reinforcement correlations were reversed. Pointers indicate the dividing line between two halves of the stimulus continuum. The graphs (X vs. square) isolate functions according to the schedule in the preceding component.

Fig. 3. Functions for individual subjects, each averaged over testing Days 4 through 12. The graphs separate data for the first and second 10 s of the fixed-interval component. The circles show mean rate throughout the 20-s trial.

oped quickly during testing. Differential responding increased throughout the testing period. Figure 2 illustrates this effect, as well as others to be discussed below. Rates shown here and elsewhere refer to the initial 20-s portion of the trial, when reinforcement was not available. Analyses omit the first trial of each session.

The phenomenon of special interest is the dimensional-contrast shoulder, which is complete only when there is a rate reversal at the extreme of the continuum. For example, dimensional contrast is not present on Days 1 to 3 for either group; it is present in the data for Days 4 to 6, but the negative shoulders are more pronounced than the positive shoulders.

Contrast tended to increase and then diminish slightly over the course of testing (Figure 2). Because our purpose was to examine factors that contribute to these shoulders, most of the following analysis was based on the middle of the testing period (Days 4 to 12). Figure 3 summarizes functions for each bird, averaged over this 9-day period. Data for the first and second halves of the trial are separated because D. Blough (1975) found a more marked effect in the first portion of the fixed interval. The present data are not consistent on that point, and response rate averaged over the entire 20-s trial (circles) provides the basis for further analysis. All subjects showed dimensional contrast; however, Bird 671 lacked the positive peak, and Bird 868, the negative trough. Contrast did not appear to be related to overall response rate; both shoulders are present in the function for Bird 640, whose rates were unusually high, and for Bird 244, whose rates were low.

If schedule-dependent local contrast contributes to dimensional contrast, the shoulders should be more marked for S(rich)/S(lean) and S(lean)/S(rich) sequences. Figures 2 and 4 address this point. There is consistent evidence for local negative contrast, appearing as relatively depressed rates in S(lean) when the preceding stimulus was S(rich) (open squares). This effect was more pronounced later in testing (Figure 2); it was present in all birds in Group H, but was clear in only one subject from Group L (Figure 4). On the other hand, positive local contrast did not appear; that is, rates in S(rich) were not consistently higher following S(lean) trials than they were following S(rich). Statistical analyses supported these conclusions: A *t* test compared mean rates in S(lean) for preceding S(rich) and S(lean) conditions. Rate was significantly lower in S(lean) following S(rich) than it was following S(lean) trials [$T(5) = 2.71, p < .05$]. By an analogous test, preceding schedule had no significant effect on rates in S(rich).

Despite the evidence for negative local contrast, there was little indication that this effect was related to the magnitude of the negative dimensional-contrast shoulder. For 5 of the 6 subjects, the rate reversal beyond the shoulder

was roughly equivalent for both types of sequence. Only the functions for Bird 704 indicate the disappearance of dimensional contrast when the conditions for local contrast were removed. Sequential effects on the magnitude of the positive shoulders are not evident.

Figure 5 examines the middle 9 testing days for additional sequential effects. Each function isolates response rate according to a particular set of preceding stimuli. One hypothesis addressed by this analysis concerns the role of stimulus factors. In paradigms that use fewer stimuli, local contrast is more pronounced when stimuli signaling the S(rich) and S(lean) components are similar (e.g., P. Blough, 1983). Thus, any contribution of local contrast to dimensional contrast should be enhanced in conditions involving similar S(rich)/S(lean) sequences. The top panel of Figure 5 analyzes the similarity effect on the positive shoulder. If similarity is important, the height of these shoulders should depend on the dimensional location of the preceding S(lean). In fact, the positive shoulders are remarkably similar. Analogously, the bottom panels do not show a similarity effect on the depth of the negative shoulder.

A second hypothesis concerns schedule-independent interactions among response rates. Stimuli correlated with relatively high average rates may depress rates during the following component; stimuli correlated with relatively low average rates may enhance rates in the following component (Malone & Rowe, 1981). Figure 5 addresses this hypothesis, inasmuch as the various ranges of preceding stimuli were correlated with different response rates. In the top panels, the squares describe the functions for preceding stimuli correlated with relatively low rates [center of the S(lean) continuum]. In the bottom panels, the squares describe the functions for preceding stimuli correlated with relatively high average rates. These functions overlap with the others in most cases; where the functions are separated, the squares fall in an intermediate range. Thus, this analysis does not suggest the presence of rate interactions.

Overall, the averaged data in Figure 5 show little or no evidence for sequential effects. The

Fig. 4. Functions for individual subjects, each averaged over Days 4 through 12. The graphs separate data according to the schedule signaled during the preceding component. The pointer indicates the dividing line between the two halves of the continuum.

similarity among these functions reflects the considerable overlap among functions for each individual subject. One possible exception is some tendency for functions to separate in mid range. This separation was present in the data for all 3 birds in Group H. The upper right panel in Figure 5 shows increasing S(lean) rates as the preceding stimuli approach the extremes

of the S(lean) continuum. An analogous effect for the positive half of the dimension appears in the lower left panel; it was present in the data for all birds in Group L. However, this relation is not apparent in the remaining data. If these sequential effects are real, they are difficult to explain by the established interactions described above.

Fig. 5. Functions isolated according to the stimuli of the preceding component. Data are averaged over testing Days 4 through 12 and over the 3 birds in each group. Pointers indicate the dividing line between the two halves of the continuum. The abbreviation "F/" stands for "following." The left panels show data for Group L and the right, for Group H. The top panels analyze effects of preceding S(lean) values and the bottom panels, of preceding S(rich) values. The preceding stimuli are grouped in overlapping sets of 4. For example, for Group L, the end S(lean) values were Stimuli 13 through 16; the center S(lean) values were Stimuli 11 through 14, and the border S(lean) values were Stimuli 9 through 12. See Table 1 for correlated wavelengths.

EXPERIMENT 2

METHOD

Because Experiment 2 reanalyzed data from a previously published report (D. Blough, 1975), this section will summarize the method only briefly. The subjects, Birds 1 and 2, were two of the three pigeons comprising Blough's Group 2 from his Experiment 1. The third bird did not learn a clear discrimination; neither Blough's 1975 report nor the present one includes its data.

The apparatus was the same as that used in the present Experiment 1. However, the neutral density wedge was not used to modify intensity; thus the stimuli varied slightly in luminance. Slits placed in front of the fiber optics cables caused the monochromatic stimuli to appear as vertical lines; their luminance was 54 cd/m². The conditioned reinforcer was a gray square on a white background.

As in the present Experiment 1, sessions consisted of 20-s trials, each signaled by onset of a stimulus wavelength. Twenty-five wavelengths ranged from 570 to 617 nm in steps of approximately equal discriminability. Reinforcement was available during a 10-s hold period following each trial; the first peck in this period turned on the gray square and occasionally was accompanied by grain presentation.

The experiment began with a series of baseline sessions, during which all stimuli were accompanied by equivalent reinforcement conditions. During the subsequent testing phase, additional trials with S- (597 nm) were superimposed on the baseline procedure with a probability of .33. The S- trials ended with the first response during the hold period; neither the gray square nor food ever accompanied responses on these added trials. Note, however, that, because 597 nm was a part of the baseline series, responses to this stimulus occasionally were reinforced.

RESULTS AND DISCUSSION

In this procedure, dimensional contrast was stronger during the first half of the trial (D. Blough, 1975, Figure 2); hence, responding during this initial period provided the basis for

analysis. The bottom panel of Figure 1, referred to earlier, describes average response rates over Sessions 3 to 10 of the testing phase. Both birds showed the dimensional-contrast effect.

Figure 6 provides sequential data for individual subjects; Figure 7 displays means. The top panels isolate the functions for components following S- (Xs) from the functions for components following S+ (squares). Because there were many fewer S- trials, the individual X functions are rather variable. Nonetheless, the comparison provides evidence for positive local contrast; rates in S+ were elevated when the preceding stimulus was S-. This summary description reflects best the data of Bird 2; for Bird 1 the rate following S- was markedly enhanced in the left shoulder, but not in other portions of the continuum. The data also indicate negative local contrast, seen in relatively depressed S- troughs following S+. Dimensional contrast is evident in the data for both preceding conditions; and, in the averaged data, there is no marked difference in the relative size of the shoulders.

The bottom panel of Figure 6 isolates functions according to the dimensional location of the preceding stimuli. If stimulus similarity were a factor, rate in S- should depend on the dimensional location of the preceding stimulus set. In fact, the depth of the trough was nearly identical under all conditions. Thus, stimulus similarity did not modify the negative local contrast effect. Because these functions also isolate high (squares) and low (circles) preceding response rates, their similarity is not consistent with the schedule-independent rate interactions suggested by Malone and Rowe (1981).

GENERAL DISCUSSION

Dimensional contrast is a robust phenomenon seen in a variety of procedures. Early research with pigeons (Catania & Gill, 1964; Farthing, 1974) used visual stimulus continua divided in half by an S+/S- boundary. A study with rats discriminating between varying intensities of white noise replicated this paradigm (P. Blough, 1980). The present Experiment 1 used a similar design. However, the

Fig. 6. Data from D. Blough (1975), reanalyzed for sequential effects. Pointers indicate the single S⁻. The left and right columns show data for Birds 1 and 2, respectively. The top panels isolate functions according to the schedule that accompanied the preceding component. The bottom panels isolate functions according to preceding regions in the S⁺ continuum. "Extremes" refer to Stimuli 1 to 7 and 19 to 25. "Shoulders" refer to Stimuli 8 to 10 and 10 to 18. "Borders" refer to Stimuli 11, 12, 14, and 15. See Table 1 for correlated wavelengths.

use of perceptually close stimuli resulted in relatively stable contrast shoulders, and a low level of reinforcement during S(lean) avoided the floor effects that have sometimes obscured the negative shoulder in previous work. Experiment 2 employed a different design that yielded conceptually similar results. Work with pigeons in another laboratory (Hinson & Malone, 1980; Hinson, Malone, McNally, & Rowe, 1978; Rowe & Malone, 1981) placed positive stimuli at each end of a line-tilt continuum and included a series of S⁻ values in between the two S⁺s. A rise in response rate in the center of the S⁻ series resulted in a W-shaped gradient that defined the dimensional contrast effect. Again, this outcome is conceptually similar, although different in form, to the demonstrations referred to above.

The use of different procedures strengthens common conclusions. Both Experiments 1 and 2 suggested that dimensional contrast does not rely on sequential effects. Rowe and Malone (1981) drew a similar conclusion from a quite different approach. To diminish schedule interactions, they introduced 30-s intertrial intervals between schedule components. The contrast effect, seen as the W-shaped gradient described above, persisted. However, unlike the present outcomes, sequential factors affected the shape of the gradient.

There are other inconsistencies between our findings and related work. In the research summarized by Malone and Rowe (1981), an important factor was stage of training. For example, in one study (Hinson & Malone, 1980) dimensional contrast depended on local con-

Fig. 7. Means over the 2 subjects whose individual data are shown in Figure 6.

trast in early (Days 17 to 19), but not late (Days 28 to 32) sessions. In the present Experiment 1, however, dimensional contrast was not dependent on local contrast even in the earliest stages of training (Figure 2). Further, our data do not indicate the amplification effect noted by Malone and attributed to the development of schedule-independent rate contrast.

The data presented here agree qualitatively, but not quantitatively, with D. Blough's (1975) model of generalization and discrimination. That model predicts the occurrence of dimensional contrast, its relatively rapid development, and its independence of local stimulus and response sequences. However, the new data presented here (Experiment 1) support previous indications (D. Blough, 1975, 1983; Rowe & Malone, 1981) that obtained shoulders are more pronounced than those predicted by the model. Clearly there are unknown factors that enhance to dimensional contrast, but local interactions between trials provide inadequate accounts.

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