Behavioral contrast redux

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Behavioral contrast is defined as a change in response rate during a stimulus associated with a constant reinforcement schedule, in inverse relation to the rates of reinforcement in the surrounding stimulus conditions. Contrast has at least two functionally separable components: local contrast, which occurs after component transition, and molar contrast. Local contrast contributes to molar contrast under some conditions, but not generally. Molar contrast is due primarily to anticipatory contrast. However, anticipatory contrast with respect to response rate has been shown to be inversely related to stimulus preference, which challenges the widely held view that contrast effects reflect changes in stimulus value owing to the reinforcement context. More recent data demonstrate that the inverse relation between response rate and preference with respect to anticipatory contrast is due to Pavlovian contingencies embedded in anticipatory contrast procedures. When those contingencies are weakened, anticipatory contrast and stimulus preference are positively related, thus reaffirming the view that the reinforcing effectiveness of a constant schedule is inversely related to the value of the context of reinforcement in which it occurs. The underlying basis of how the context of reinforcement controls reinforcement value remains uncertain, although clear parallels exist between contrast and the effects of contingency in both Pavlovian and operant conditioning.

Contrast is a ubiquitous concept in experimental psychology. Most well known are contrast effects with respect to sensory systems, exemplified by color and brightness contrast. In other areas of psychology, the concept of adaptation level has wide applicability. In all of these domains, the effect of a given stimulus value seemingly involves a comparison process such that the psychological impact of a stimulus is due not solely to its absolute value, but also to its value relative to that of other stimuli presented either in the same context or in the past. Although the empirical phenomenon of contrast is pervasive, whether it is regarded as a basic psychological process or, instead, is to be explained in terms of more fundamental mechanisms varies widely across different areas of psychology.

REINFORCEMENT CONTRAST: A BRIEF HISTORY

The concept of contrast has played a major role in reinforcement theory, both in generating voluminous research and in posing theoretical challenges. There are two major classes of contrast, with relatively separate experimental literatures. Successive contrast is said to occur when the level of behavior maintained by a given reward outcome varies with the nature of the reward outcome previously presented. The most well known example was reported by Crespi (1942). The running speeds in a straight alley of rats main-

tained on a constant level of reward amount were compared with those of other rats for which the same amount of reward was presented either after experience with a smaller reward or after experience with a larger reward. Subjects shifted from a smaller amount ran faster than subjects with the constant amount throughout, which Crespi labeled an *elation effect*, whereas rats shifted from a larger amount ran slower than those with the constant amount throughout, which was labeled a *depression effect*. As a result of these and similar findings, Hullian learning theory modified the concept of incentive (the K parameter) to become a performance variable, which ultimately made it difficult to distinguish the Hullian account from other competing accounts explicitly cognitive in nature. Successive contrast effects have continued to be investigated widely even with the decline in influence of Hullian learning theory, often in the context of physiological manipulations to assess their underlying basis. Because Flaherty (1996) has provided a comprehensive review of this literature, no further account will be provided here.

The second type of contrast procedure is when the behavior produced by a constant reward payoff is affected by the reward conditions that are alternately presented for the same response under different stimulus conditions. This procedure is sometimes labeled *simultaneous contrast*, a misnomer because the different reward conditions are not simultaneously present. However, the different conditions do occur in close temporal proximity, whereas in the successive contrast procedure the different reward conditions are often experienced with significant temporal separations. Although simultaneous contrast research has been conducted in runway situations comparable with that used by Crespi (1942), the great majority has occurred in free-

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operant procedures known as multiple schedules, in which rates of reward have been varied, rather than different amounts.

Multiple schedules using response rate as the primary datum became widely used in the 1950s for studies of stimulus generalization and discrimination. The observation that response rate increased to the S+ with a constant reinforcement schedule at the same time that response rate to the S- decreased (Hanson, 1959; Smith & Hoy, 1954) received substantial attention because it seemed to contradict the classic account of discrimination learning by Spence (1937) in terms of interacting stimulus generalization gradients. That is, to the extent that the S+ and the S- were physically similar, training an animal not to respond to the S- should produce generalized inhibition to the S+ stimulus and, therefore, should reduce response rate, not increase it.

The prototypical example of *behavioral contrast* was provided by Reynolds (1961). Red and green keylights were alternated every 3 min, each initially associated with a variable-interval (VI) 3-min schedule. The schedule during one of the keylights was changed to extinction, with the result that response rate in the alternative keylight, for which the schedule of reinforcement remained constant, substantially increased.

Initially, the most prominent analysis of why contrast occurred was based on the excitatory effects of nonreinforced responding (Terrace, 1963, 1966), but later the concept of contrast was wedded with the concept of relative rate of reinforcement and eventually encompassed within the explanatory domain of Herrnstein's (1970) matching law. A variety of other explanatory approaches were developed in the ensuing decade, several of which will be discussed later in this paper. But first, it is useful to delineate several empirical phenomena that are critical to any theoretical account.

SEPARABLE COMPONENTS OF BEHAVIORAL CONTRAST

Local Versus Molar Contrast

A major source of theoretical confusion has been that there are different types of contrast with different functional properties. One important early distinction was between local contrast and molar contrast. Molar contrast refers to the change in average response rate during the unchanged component as a function of the change in reinforcement in the alternating component. Local contrast refers to the larger change in response rate that is evident at the beginning of the constant component just after the termination of the alternated component. Local contrast has also been indexed in discrimination procedures in which the S+ and S- have been randomly alternated by the difference in response rate during the S+ following a preceding S+ component versus the response rate during the S+ following a preceding S- component.

There is strong reason to believe that the determinants of local contrast are different from those of molar contrast and

that the contribution of the local contrast effect to molar contrast varies with the experimental parameters. Terrace (1966) reported that both local contrast and molar contrast were maximal in the early stages of discrimination training when a large amount of nonreinforced S- responding occurred but that, as the S- response rate decreased, both types of contrast disappeared. Other studies have reported that the maximum rate of responding occurred in the first few sessions of discrimination training and then declined, but the stable asymptotic response rate still was above the baseline level, indicating that local contrast is often a transitory phenomenon, whereas molar contrast persists indefinitely (Bloomfield, 1966; Mackintosh, Little, & Lord, 1972; Malone, 1976; Nevin & Shettleworth, 1966; Selekman, 1973). An important procedural feature used by Terrace (1966), but not by subsequent investigators, was that the transition from the S- to the S+ occurred only after a specified time period, during which no S- responding occurred. This meant that the duration of the S- was much longer early in training, as was the amount of S- responding. Thus, the reduction in contrast with continued training reported by Terrace (1966) could have been due to either of those variables.

The importance of distinguishing between local and molar contrast is exemplified by the effects of the similarity of the stimuli being discriminated as S+ versus S-. Local positive contrast appears to be primarily a function of the amount of responding to the S- (Blough 1983; Malone, 1976). Thus, the extent of discrimination training is one important variable, although the similarity of the S+ and S- should also be important. Various studies of stimulus similarity have yielded conflicting results. Some have reported both larger molar and larger local contrast effects with greater similarity (Blough, 1980, 1983; Hearst, 1969); others (Mackintosh et al., 1972; Malone, 1976; White, Pipe, & McLean, 1983, 1984) have reported the opposite effect (greater contrast with less similar stimuli). Such disparate results suggest that the function relating stimulus similarity to contrast is nonmonotonic, which typically is due to separate underlying functional relationships being combined. Highly similar stimuli should produce substantial local contrast owing to the high rate of nonreinforced responding to the S- engendered by its similarity to the S+. However, in the limiting case in which the S+ and S- are identical, no contrast should occur, because of a complete failure of discrimination. Increases in the physical difference between the stimuli should increase contrast, because some degree of discrimination occurs, but still with considerable S- responding, whereas further decreases in stimulus similarity should attenuate any confusion between the stimuli, thus reducing S- responding and local contrast but enhancing the size of the molar contrast effect that depends on the increased discrimination of the different reinforcement rates associated with the different stimuli. Whether stimulus similarity is positively or negatively related to occurrence of molar contrast thus should depend on which region of the similarity dimension is used. In sup-

port of this possibility, studies showing greater local contrast with greater stimulus differences have also reported the complete absence of local contrast when the S+ was alternated with periods of time-out (in which no nonreinforced responding occurred), coupled with a generally lower degree of molar contrast, as compared with when an explicit S- was used (Mackintosh et al., 1972; Malone, 1976). To the extent that time-out is a cue for extinction that is maximally different from the cue for positive reinforcement, such effects suggest that the different effects of stimulus similarity previously obtained may indeed be due to the varying contribution of local contrast to molar contrast effects.

The majority of studies in which the effects of stimulus similarity on contrast have been investigated have varied similarity within a single dimension—most frequently, line orientation or variations in color. The maximum degree of dissimilarity has been a comparison between lines differing in orientation by 90° or between two colors (e.g., red vs. green). To the extent that the function relating local contrast is indeed nonmonotonic, this degree of physical separation may not be sufficient to sample both sides around the inflection point of the function. Williams (1988b, Experiment 1) thus compared the degree of local and molar contrast with intradimensional versus extradimensional discriminations for the same subjects. For one set of experimental conditions, the discriminative stimuli were three vertical lines versus a yellow keylight. For a second set of conditions, the three vertical lines were alternated with three horizontal lines. The vertical lines were always cor-

related with a constant VI 90-sec schedule. The schedule of reinforcement for the yellow keylight and horizontal lines was varied between VI 30-sec and VI 270-sec. The degree of contrast was assessed by comparing the response rates to the vertical lines as a function of the rate of reinforcement in the alternative stimulus. Figure 1 shows the log of the ratio of the rates to the vertical lines when the alternative schedule was VI 270-sec versus when the alternative schedule was VI 30-sec. Shown separately are the contrast effects, subdivided into 6-sec bins (total component duration was 30 sec), for the first 10 sessions of an experimental condition and for the last 10 sessions (training continued for 30 or 40 sessions), thus allowing an index of the effects of continued discrimination training.

If the two functions for the vertical versus the horizontal line discriminations are compared, the contrast effect during the early sessions was greatest at the onset of the VI 90-sec schedule and then monotonically decreased across the component. Late in training, the function was essentially flat throughout the component. The change in the slope was correlated with a reduction in overall contrast. For the vertical line versus yellow discrimination, during the first 10 sessions contrast was also greatest at the onset of the VI 90-sec component and monotonically decreased, with the average size of the contrast effect in this condition being below the average size of the contrast effect for the line-tilt discrimination. Late in training, however, the average contrast effect was larger for the line versus color discrimination, and the pattern of its response rate within the component reversed as well. Whereas early in training the

Figure 1. Contrast effects from Williams (1988b). Separate functions are for the initial 10 sessions and the last 10 sessions of training for a line orientation discrimination (V vs. H) and for a color versus line orientation discrimination (V vs. Y). Results are the means of 4 subjects.

contrast gradient was similar in shape to that from the line-tilt discrimination, late in training the smallest contrast effect occurred just after the onset of the vertical lines, and the size of the contrast effect increased as the component progressed. This latter effect represents *anticipatory contrast*, which will be discussed in the next section. The important observation for present purposes is that, early in discrimination training, when local contrast should be greatest, both local and molar contrast are enhanced by more similar stimuli but that, later in discrimination training, when local contrast has disappeared, greater contrast occurs with more dissimilar stimuli. The implication is that local and molar contrast are due to different mechanisms. If local contrast is not isolated from molar contrast, therefore, any general analysis of the determinants of molar contrast will be problematic.

Molar Versus Anticipatory Contrast

Figure 1 shows that the size and pattern of the contrast effect across the constant component changed systematically with continued discrimination training, so that the maximum contrast effect occurred toward the end of the component prior to the change in reinforcement rate at the point of component transition. Williams (1974) and Buck, Rothstein, and Williams (1975) referred to this finding as the *following-schedule effect*, but subsequently the terminology was changed to *anticipatory contrast* in order to emphasize its similarity to anticipatory contrast in consummatory licking procedures (see Flaherty, 1996). The issues posed are what role does anticipatory contrast play in behavioral contrast generally and what are its determinants?

Evidence for anticipatory contrast was first published by Pliskoff (1961, 1963) and was reported in a subsequent study by Wilton and Gay (1969). I "rediscovered" the phenomenon accidentally while studying successive discrimination learning for other reasons (Williams, 1974). At the time, I was unaware of the previous findings, because contrast was a very active area of research during the early 1970s and none of the theories in the focus of attention cited the earlier work, perhaps because anticipatory contrast contradicted their basic theoretical assumptions. It was also the case, although never published, that several investigators attempted but failed to replicate the earlier work (George Reynolds, personal communication, 1975). After publishing a follow-up study in which we provided more detailed information about the changes in local response rate (Buck, Rothstein, & Williams, 1975), I soon learned that skepticism about the reliability of the effect still prevailed. One reason is suggested by the results shown in Figure 1: Whether anticipatory contrast occurs depends both on the extent of discrimination of training and on the similarity between the discriminative stimuli. Moreover, we now know that seemingly trivial procedural variations, such as whether the keylight stimuli change in location or are constant and whether there is a brief flash of the keylight as feedback for each response (White, 1995), may play a significant role in determining whether anticipatory con-

trast occurs, presumably because they affect stimulus similarity. But perhaps the most important problem was that our early attempts to study anticipatory contrast used changes in local response rate as the primary datum, an unfortunate choice because the pattern of local response rate is affected by numerous variables, including hysteresis effects from previous conditions and the duration of the schedule components (e.g., Williams, 1983, Figure 6). More generally, reflections of anticipatory contrast in local response gradients depend on the discrimination of the temporal location of the end of the component, which may or may not occur, depending on the duration of the component, and the salient events occurring during a given component presentation that compete for stimulus control (e.g., the number of reinforcers in a given component presentation).

Because of the complex determinants of local response rate patterns, we switched to using different sequences of reinforcement schedules to separate the different types of contrast. One such sequence was a recycling three-component schedule (AXB) in which the reinforcement schedules during A and B were equal and constant, whereas that during X was varied (Williams, 1981, Experiment 2; Williams, 1988b, Experiment 2; Williams, 1989a, Experiment 2; Williams & Wixted, 1986). The issue was whether response rate would be differentially affected in A and B by a change in reinforcement in Component X. Both components should show contrast if changes in molar relative rate of reinforcement were the controlling variable, whereas a greater contrast effect in Component A would reflect anticipatory contrast and a greater change in Component B would reflect local contrast owing to the preceding component. The consistent result has been that anticipatory contrast is generally robust, although Williams (1988b, Experiment 2) showed that it was substantially attenuated by the use of similar discriminative stimuli. The results during Component B have been more variable. Some subjects show a persistent contrast effect, some show none at all, whereas others have an initial effect that disappears with continued training.

The second component sequence we have used has been A-X, B-Y, where A and B are target components with equal constant schedules, whereas X has a lower reinforcement rate (typically, extinction) and Y has a higher reinforcement rate. When the A-X and B-Y pairs are randomly interspersed, contrast owing to changes in molar relative reinforcement is eliminated, as is differential local contrast, because A and B are preceded equally often by X and Y. Anticipatory contrast effects with this procedure are typically robust, enhanced by stimulus dissimilarity, and increase with continued training. In comparison, when the opposite sequential arrangement has been used (X-A, Y-B) in order to isolate the effect of the preceding component (local contrast), no consistent differences in response rate in A and B have been obtained (Williams, 1979, Experiment 1, 1991), although this finding must be qualified by the caveat that highly experienced subjects and highly discriminable stimuli were used in those experiments.

Figure 2. Mean response rates from Williams (1976). On the left side are response rates from the constant component; on the right side are the response rates from the variable component, which varied across conditions in terms of the location of the reinforcer.

The general conclusions from the above-described experiments have been that anticipatory contrast accounts for a substantial portion of steady-state molar contrast, but it is unclear whether there is any molar contrast effect apart from anticipatory contrast. Local contrast effects are generally transitory, although they may be substantial and enduring under circumscribed conditions. Local contrast also depends on different psychological processes than does anticipatory contrast, principally the occurrence of nonreinforced responding during the process of discrimination, as opposed to the putative processes of anticipatory contrast, which I will discuss below.

MECHANISMS OF ANTICIPATORY CONTRAST

Part of the skepticism about anticipatory contrast is generated by its apparent implication that the pigeon is anticipating the future and comparing the current state of affairs with that which lies just ahead. Such an “explanation” implies two cognitive acts, anticipation and comparison, which have not resonated with the general theoretical framework of behavioral analysis. Theoretical posture aside, the critical issue is whether we can define the variables that control anticipatory contrast in order to understand the underlying mechanisms.

My first conjecture was that it involved an interaction between successive reinforcers, modeled in part on Catania’s (1973) idea of *inhibition by reinforcement*. That is, the effectiveness of a reinforcer perhaps varies with the amount

of time after the reinforcer’s presentation before another significant event occurs. Metaphorically, we might refer to this as a consolidation process, not unlike the findings of Allan Wagner and his colleagues on the role of rehearsal processes in Pavlovian conditioning (Wagner, Rudy, & Whitlow, 1973).

To test this idea, Williams (1976) trained pigeons on a multiple schedule with alternating 90-sec components. Initially, the schedule was VI 90-sec in each component, so that, on average, one reinforcer was delivered per component presentation. Then the schedule in one of the components was changed so that a single reinforcer was presented during each component presentation, leaving the molar relative rate of reinforcement unchanged. The location of the single reinforcer was varied across conditions, occurring 5, 45, or 80 sec after the onset of the component. After the reinforcer was obtained, extinction was in effect for the remainder of the 90-sec component. Thus, the new schedule within the variable component was a mixed fixed-interval (FI) EXT, with the value of the FI corresponding to the temporal locations of the single reinforcers. If anticipatory contrast occurs because the reinforcers from the unchanged VI 90-sec schedule are inhibited in effectiveness by subsequent reinforcers close in time, whether positive or negative contrast should occur depends on the temporal proximity of the reinforcers in the alternative component, relative to the average temporal proximity during the baseline training. Changing the location of the reinforcers in the following component should therefore affect the degree of inhibition of the reinforcers in the tar-

Figure 3. Local response rates for individual subjects across the different segments of the constant component as a function of the reinforcer location in the variable component. From "Behavioral Contrast as a Function of the Temporal Location of Reinforcement," by B. A. Williams, 1976, *Journal of the Experimental Analysis of Behavior*, 26, p. 62. Copyright 1976 by the Society of the Experimental Analysis of Behavior. Reprinted with permission.

get component. When the reinforcers from the following component occur 5 sec after the end of the target component, any reinforcers near the end of the target component should be substantially inhibited. When the reinforcers from the variable component occur 80 sec after the end of the target component, the degree of inhibition should be less than that during baseline training, in which the reinforcers in the following component could occur at any point after the target component, including immediately afterwards. Thus, response rate in the target component should decrease when the following schedule is FI 5-sec and increase when the following schedule is FI 80-sec. Changing the value to FI 45-sec should be intermediate, with little change in response rate, because the average time following a reinforcer from the target component would be the same as that during baseline training. However, the latter prediction depends on the specific function relating temporal proximity of the succeeding reinforcer to the degree of inhibition; for example, the function might be hyperbolic, like that for delay of reinforcement, so that only the successive reinforcers that occurred relatively soon would have inhibitory properties.

Average response rates in the three components are shown in Figure 2. As was predicted, there was a small negative contrast effect in the FI 5-sec condition and a small positive contrast effect in the FI 80-sec condition, both of which were statistically significant. There was also a non-significant positive contrast effect in the FI 45-sec condition. Figure 2 also shows the response rates in the variable component. Here, response rates for all three schedules

were less than that during the baseline condition, with the greatest reduction in the FI 5-sec condition. In general there was an inverse relation between the reduction in responding and response rate in the constant component, which suggests that *active inhibition* of responding was not a controlling variable.

Figure 3 shows the local response rates for individual subjects within the constant component as a function of FI schedule in the variable component. Whereas response generally increased throughout the component for the FI 45-sec and FI 80-sec conditions, response rate decreased in the FI 5-sec condition. The result was that the difference in the average response rate seen in Figure 2 was due primarily to differences toward the end of the component, thus supporting the hypothesis that the location of the reinforcer in the following component was the critical variable.

The results of Williams (1976) provide support for the *inhibition-by-reinforcement* hypothesis, but they are not definitive. The reason is that the subjects clearly had a temporal discrimination of the location of the reinforcer in the variable component. This was seen most clearly with the FI 5-sec schedule, where response rate was high for the first 5 sec of the component, until the reinforcer was obtained, and then dropped to near-zero rates for the remainder of the component. Conversely, response rates in the beginning of the FI 45-sec and FI 80-sec components were initially low and gradually increased. The result of such temporal discrimination was that the schedule became functionally like a multiple FI EXT, so it is unclear whether

Figure 4. Mean response rates in the two target components of the A-X, B-Y schedule sequence (circles; Williams, 1979, Experiment 2). Also shown is the discrimination index for the two following components (xs). The multiple versus mixed designation refers to whether the different following schedules had the same versus different discriminative stimuli. From "Contrast, Component Duration, and the Following Schedule of Reinforcement," by B. A. Williams, 1979, *Journal of Experimental Psychology: Animal Behavior Processes*, 5, p. 389. Copyright 1979 by the American Psychological Association. Reprinted with permission.

the controlling variable was the location of the reinforcer in the following component or the *value* of the stimulus associated with that component.

Strong evidence against the inhibition-by-reinforcement account was provided by Williams (1979, Experiment 2), using an extension of the A-X, B-Y procedure described above. In the initial use of that procedure, X and Y not only had differential reinforcement schedules, but also had differential stimuli. But if the X and Y components were associated with the same stimulus, that stimulus should have the same average value following A and B. On the other hand, A and B still would be followed by the differential occurrence of reinforcement in their respective following components. Anticipatory contrast was first established with differential stimuli in X and Y (first segment of Figure 4), and then the stimulus for the extinction component was changed to that of the richer following schedule. Anticipatory contrast disappeared in the first four sessions after this stimulus change, followed by a reliable effect in the opposite direction, as is shown in Figure 4. When the differential stimuli in the X and Y components were reinstated (last segment of Figure 4), anticipatory contrast was again evident. Thus, anticipatory contrast depends on a comparison of the reinforcement schedule during the target component and the average value of the stimulus in the

following component, as manifested by the rate of responding, regardless of whether reinforcers themselves actually occur following the target component.

A shortcoming in the experimental design just described is that the differential reinforcement schedules in the X and Y components, although associated with the same nominal stimulus, can be discriminated on the basis of the target components that precede them. That is, X always follows A, and Y always follows B, so that a conditional discrimination may be learned that produces differential response rates between X and Y. As a result, the reversal of response rates in the target components seen in the second segment of Figure 4 eventually disappears. Most typically, results for individual subjects are highly variable (see Williams, 1990b, 1992b, Experiment 1).

A second experimental variation of the signaling conditions in the differential following components (X and Y) has produced a conundrum. In one set of conditions (Williams, 1979, 1981), a signaled VI schedule was substituted for the usual unsignaled VI in the richer following component. The stimulus in the absence of the signal indicating a VI reinforcer was available was the same as that correlated with extinction in the alternative following component. Because subjects seldom responded except when the signal was present, response rate in the rich following

Figure 5. Mean response rates in the target components of the A-X, B-Y schedule sequence in Williams (1979, Experiment 3). From "Contrast, Component Duration, and the Following Schedule of Reinforcement," by B. A. Williams, 1979, *Journal of Experimental Psychology: Animal Behavior Processes*, 5, p. 392. Copyright 1979 by the American Psychological Association. Reprinted with permission.

component was very low and comparable to that during the extinction component. Yet, a robust anticipatory contrast effect did occur, as is shown in Figure 5. As can be seen in its first three segments, the change from the unsignaled VI to the signaled VI in the rich following component did not disrupt anticipatory contrast, and the contrast effect quickly reversed when the target component preceding the signaled VI was reversed. The final segment of Figure 5 shows the effect of returning to the unsignaled VI and presenting the same stimulus in both the extinction and the rich following components. In that condition, anticipatory contrast quickly disappeared, and response rates in the two target components then reversed.

The procedural differences that produced the different outcomes in the last two panels of Figure 5 deserve to be highlighted. For the last condition, the two following components had differential reinforcement rates (a rich VI schedule vs. extinction) but the same stimulus conditions, except for the occurrence of food. Response rate was also similar in the two components. With the signaled VI schedule in the rich following component (Y), the two following components had similar response rates, and the stimulus conditions were highly similar as well, the only difference being the occasional occurrence of the signal for food and then food delivery itself. It seems odd that the addition of the very brief signal presentation should determine whether or not anticipatory contrast occurred.

One possible interpretation of the differential occurrence of anticipatory contrast in the just-described experiments is that the common stimulus in the two following components had different values. For the fourth condition in Figure 5 and in similar experiments (Williams, 1979, Experiment 2, and 1990b), the stimulus present in both following components was high in value, as is shown by high

response rates whenever it was present. When the schedules in the following components were signaled VI versus extinction, the stimulus present most of the time was that correlated with extinction, and therefore, very little responding occurred. Further research is needed to determine whether this is indeed the cause of the different outcomes and also to understand its implications for the necessary conditions for producing anticipatory contrast.

THE PARADOX OF ANTICIPATORY CONTRAST

In the A-X, B-Y experimental design, different response rates occur during the two target components, because the A and B stimuli predict differential following schedules: Typically, A predicts a period of extinction, whereas B predicts an impending higher rate of reinforcement. But the potential of A and B to predict their different following schedules entails that the stimulus that predicts the improvement in reinforcement rate should normally elicit an increased response rate, in much the same way as occurs in autoshaping procedures. Similarly, the stimulus that predicts impending extinction should become a conditioned inhibitor. That is, the Pavlovian relationships between the target stimuli and their differential following stimuli predict a result opposite to anticipatory contrast. Anticipatory contrast implies a comparison between the reinforcement rates in the target components and their following stimuli, with this comparison process apparently antagonistic to the predictive relation that ordinarily would result in a Pavlovian association. The fact that a Pavlovian association and a comparison process between the reinforcement rates in the target component and its following component are both engendered by the same sequential arrangement of

Figure 6. Mean response rates during the target components of the A-X, B-Y procedure of Williams (1992b). The initial training phase had no food in the A and B components. The second and fourth phases had the same stimuli in the X and Y components. See the text for details.

events seemingly implies that there are two separate types of *predictiveness*: that which produces a direct association with the following conditions of reinforcement and that which provides a discriminative cue for the following schedule, allowing it to be compared with the schedule in progress. The fundamental problem with a theoretical analysis of anticipatory contrast is how the learned relation that produces the comparison process should be characterized. Before that issue can be addressed, however, it is important to establish that two separate processes actually are involved in anticipatory contrast procedures.

It is now clear that Pavlovian associations may occur in the A-X, B-Y procedure and that those associations generate responding to the target stimulus predicting the higher value following schedule that potentially competes with anticipatory contrast. Williams (1992b, Experiment 1) first presented the A-X, B-Y procedure with the same common stimulus in the X and Y components and extinction in the A and B target components. This is an autoshaping procedure similar to that used by Brown, Hemmes, Coleman, Hassin, and Goldhammer (1982), and like their results, pecking occurred only during the target component that led to a VI 30-sec food schedule in its following component (see the first segment of Figure 6). In Phase 2 of the experiment, the stimulus conditions remained the same, but a VI 2-min schedule was added during the two target components. Whereas response rate increased in both target components because of the added response-food contingency, substantially more responding again occurred in the target leading to the VI 30-sec following

schedule. The third phase of the experiment introduced differential stimuli in the two following components, with the result that the *autoshaping* effect was replaced by anticipatory contrast, with higher response rates in the target followed by extinction. Finally, Phase 4 replicated the procedure of Phase 2, but now anticipatory contrast continued to occur. This latter effect indicates that the anticipatory contrast effect may not be reversible when the differential stimuli in the two following components were removed. But it should be noted that a high level of discrimination between the X and the Y following schedules continued to occur, indicating that sources of stimulus control were available other than the keylight stimuli.

Further evidence for the role of Pavlovian associations in the anticipatory contrast procedure comes from measures of stimulus preference. When the A and B target stimuli from the A-X, B-Y procedure are presented together in brief probe trials, preference is strongly in favor of B, despite the substantially greater response rate for A during the baseline training (Williams, 1991, 1992c). Thus, the change in procedure from one keylight's being available to two keylights' being available reverses the order of rate of responding in the two components. The issue raised is how the disparity in these two different measures of *stimulus value* is to be understood. One possibility is that the increase in response rate in the A target component does not reflect an increase in value but, instead, arousal effects that are due to generalized emotionality effects. Then, during probe tests, these arousal effects might be distributed equally to the two choice alternatives, so that the Pavlovian

Figure 7. The sequence of component schedules in the modification of the A-X, B-Y procedure used by Williams and McDevitt (2001). The A and B target components involved two link chains such that food occurred only during the second segment of the chain.

associations of A with X and B with Y are expressed in terms of a preference for B.

An alternative interpretation of the dissociation of single-stimulus response rate and preference on the probe trials is that anticipatory contrast and preference owing to Pavlovian associations are separate phenomena that compete for expression in both behavioral measures. Thus, in the A-X, B-Y procedure, the anticipatory contrast effect evidenced by a higher response rate during A may in fact have been reduced because some amount of responding to B occurred owing to the Pavlovian contingency. Similarly, the preference for B during the brief probe tests may have been underestimated because the anticipatory contrast effect with respect to response rate intruded into the probe tests. Such an interpretation is meaningful only if it is possible to dissociate these separate behavioral processes experimentally.

Clear functional dissociation with respect to the duration of training was reported by Williams (1991, Experiment 2). Here, the probe preference tests were presented at regular points throughout training on the A-X, B-Y procedure.

Because of a prior training history, anticipatory contrast developed very slowly and was statistically reliable only after 25–30 sessions of training. However, strong preference for the B stimulus was at its maximum after only 10 sessions of training (the time of the first probe test) and remained constant throughout training.

We have now developed a procedure that reconciles the anticipatory contrast and preference measures (Williams & McDevitt, 2001). As is outlined in Figure 7, the simple VI schedules used previously in the target components of the A-X, B-Y procedure were replaced by chain schedules, designated as A1–A2–X and B1–B2–Y. During the initial links of the chains (A1 and B1), no food was available, but responding was necessary to advance to the succeeding link. During the A2 and B2 links of the target components, a VI 2-min food schedule operated. The total duration of the two links of each chain was 1 min. As in previous studies, the X component was associated with extinction, and the Y component was associated with a richer VI.

Figure 8 shows relative response rates during the A1 versus the B1 components and during the A2 versus the B2

Figure 8. Relative response rates for the A target component for individual subjects during training with the procedure shown in Figure 7. The left-hand functions correspond to the initial segments of the target components; the right-hand functions correspond to the terminal segments of the target components. Relative rates greater than .5 correspond to higher response rates in the A target component.

Figure 9. Responses per minute (top panel) in the different links of the two target component taken from the last 10 sessions of training. Preference for the A target component is presented in the bottom panel. Results for the initial links and the terminal links of the chains are shown separately.

components for individual subjects. Response rate was higher during B1, which led eventually to the richer following schedule. Presumably, this was due to the Pavlovian association. With respect to the terminal links of the chains, response rate was higher during A2, which is consistent with anticipatory contrast.

Figure 9 provides the mean response rates for each of the links of the chain, along with the preference results obtained when either the two initial-link stimuli or the two terminal-link stimuli were paired together during probe tests. Preference was in favor of B1 over A1, consistent with the response rate results shown in the top panel of the figure. Preference was in favor of A2 over B2, again consistent with the response rate results.

Given that response rate and preference in this new procedure were positively correlated, it is of interest to assess why a negative correlation was obtained in previous studies with the simpler A–X, B–Y procedure. Two procedural differences are evident. The first is that no food was avail-

able in the initial links of the chains. This perhaps explains the initial-link results, because contrast presumably requires a comparison between the reinforcement rate in the target stimulus and that in the following component. Thus, only the Pavlovian relation was operative, and both response rate and preference were apparently controlled by that relationship. A more complex explanation is required for the positive correlation between response rate and preference for the terminal-link stimuli, given that the terminal links of the A and B chains were essentially similar to the simple A and B schedules used in previous studies in which a strong inverse relation occurred between response rate and preference. The most plausible interpretation is that the putative Pavlovian association between B2 and Y (the richer schedule) was overshadowed by the B1–Y association. Because of the attenuation of the B2–Y association, anticipatory contrast received less competition from the Pavlovian process and thus was expressed both in terms of response rate and in terms of preference.

The possible role of overshadowing of the Pavlovian association between the target component stimuli and their respective following schedules may also elucidate the paradoxical results described in the previous section. In the basic A–X, B–Y contrast procedure, the different following schedules were differentially cued by their own keylight stimuli. Such stimuli might then overshadow the Pavlovian associations between the target stimuli and the reinforcers delivered in the components that followed. By this account, when the different following schedules were associated with the same stimulus, that stimulus had minimal predictive value, so that the predictive relations between the target stimuli and their respective following schedules were no longer overshadowed, with the result that the Pavlovian relation became a stronger determinant of response rate during the target components. Furthermore, the reason contrast occurred with the signaled VI in the rich following component is that the signal overshadowed that predictive relation between the target stimulus and the reinforcers in its following component, just as did the stimulus associated with the richer following schedule when an unsignaled VI was used.

Competition between Pavlovian contingencies and the dynamics of contrast is also evident when the response showing contrast is consummatory licking, the other major procedure used to study anticipatory contrast. Flaherty (1996) has reviewed an extensive series of experiments in which rats lick a drinking tube containing a saccharin solution for a period of minutes, which is then followed by a second drinking tube that contains either more of the same saccharin solution or, for a second group of subjects, some highly preferred sucrose solution. Licking rate to the first drinking tube is substantially suppressed when the second drinking tube contains sucrose.

Although the preponderance of anticipatory contrast experiments using the consummatory licking procedure have used between-groups experimental designs, it also occurs with within-subjects designs in which the different follow-

ing solutions are presented on different days, cued by different sets of contextual cues (Flaherty & Rowan, 1985). However, when within-subjects designs have been used in which the target solutions were cued by different flavors, anticipatory contrast was not obtained (Flaherty, Copotelli, Grigson, Mitchell, & Flaherty, 1995; Lucas & Timberlake, 1992). Moreover, when rats were given a preference test between the different flavors, a strong preference occurred in favor of the flavor that predicted the preferred following solution. These differences between environmental and taste cues are most readily understood in terms of the preferential Pavlovian associations between tastes and food. Because of the *prepared* nature of those associations, Pavlovian conditioning rapidly occurs when the target solution is cued by a taste, which increases the preference for that solution and overwhelms the contrast effect that normally occurs when environmental cues predict the richer following schedule.

Not only may Pavlovian associations compete with the expression of anticipatory contrast, so also may associations between the operant response and the rich following schedule. This is perhaps related to a difference in the discrimination procedures typically used in experiments involving rats versus pigeons. A common feature of experiments involving rats is that S+ trials are allowed to follow S- trials only after some minimum time during the S- without a response, in order to prevent S- responding from being superstitiously reinforced by S+ onset. Experiments with pigeons have generally not incorporated this feature, because pigeons usually do not show such superstitious conditioning. Williams (1990a) argued that such differences were important for understanding why anticipatory contrast did not occur with rats receiving the A-X, B-Y procedure that routinely demonstrated anticipatory contrast with pigeons. Instead, the target component that led to the richer following schedule had a significantly higher response rate. This is puzzling, given that the demonstration of anticipatory contrast with the consummatory licking procedure has involved rats as subjects. Moreover, Baccotti (1976) demonstrated anticipatory negative contrast with leverpressing by rats, in that immediate postsession feedings suppressed behavior toward the end of the daily sessions, whereas delayed postsession feedings did not. Using these other procedures as models, Williams (1992a) trained rats in each session with a single 10-min stimulus presentation in which a VI 1-min schedule operated, followed by a second 10-min presentation in which either an FR-1 or an extinction schedule operated. Different auditory stimuli were correlated with the VI 1-min schedule, depending on whether the following schedule was FR-1 or EXT, which themselves were also differentially cued. The FR-1 versus EXT following schedules were alternated across sessions. Response rates were higher during the VI 1-min stimulus followed by extinction—that is, anticipatory contrast. However, when three cycles of each sequence were interspersed across a session, anticipatory contrast failed to occur. But a substantial trend toward anticipatory

contrast did occur when a 10-sec time-out separated the target components from their respective following schedules, presumably because it reduced the opportunity for adventitious reinforcement.

Anticipatory contrast has also been studied in combination with an explicit response contingency for transition to the following component. Nevin, Smith, and Roberts (1987) and Williams (1988a) compared the degree of anticipatory contrast in the A-X, B-Y procedure either with a fixed-time target component duration (the usual procedure) or with the target components terminating only after an FI response requirement had been fulfilled. Imposition of the response contingency for component transition reduced the amount of anticipatory contrast, but a substantial contrast effect nevertheless remained.

Further evidence for the role of the response contingency comes again from the consummatory licking anticipatory contrast procedure. Flaherty and Grigson (1988) demonstrated that when a FR response requirement was required for the transition from the target saccharin solution to the preferred sucrose solution, the anticipatory contrast effect was abolished and replaced by a reinforcement effect (i.e., saccharin licking was increased). In order for anticipatory contrast to be manifest, therefore, it must be stronger than both the Pavlovian signaling effects and whatever associative relations there may be between responding in the target component and transition to the following schedule.

THEORETICAL EXPLANATIONS OF CONTRAST

The determinants of anticipatory contrast have been considered in detail because it appears to be the major component of contrast generally, at least with respect to molar steady-state contrast with highly discriminable stimuli. Moreover, none of the major explanations of contrast provides a coherent basis for understanding why anticipatory contrast occurs. But before considering those various theoretical accounts, most of which have not notably advanced since the review by Williams (1983), it is first appropriate to consider accounts of contrast that view it not as a fundamental phenomenon of major theoretical interest but, rather, as a byproduct of confounding variables operating in contrast procedures.

Changes in Interresponse Time Pattern

The first account of this type suggests that positive behavioral contrast is the result of adventitious reinforcement of short interresponse times (IRTs). The result of discrimination between an S+ and an S- is local contrast at the onset of the S+, which is reflected in bursts of short IRTs, presumably owing to emotionality effects of nonreinforced responding to the S-. Reinforcers occurring later in the component thus become more likely to follow short IRTs than do those occurring during baseline training. Even when local contrast disappears with continued discrimination training, the short IRTs persist because of their con-

tinued adventitious reinforcement (Mackintosh, 1974a, p. 374). Perhaps related to an IRT analysis is that behavioral contrast does not occur in discrete-trial procedures in which response latency is the dependent variable (Mackintosh, 1974b). Moreover, when a free-operant procedure was used, in which robust positive contrast occurred, there still was no evidence of contrast with respect to the latency of the first response in the target component with the constant schedule.

Although such an IRT analysis may be relevant to some forms of contrast, it clearly cannot explain cases of steady-state contrast that occur in the absence of local contrast—notably, contrast when a constant VI component is alternated with a time-out or blackout in which no responding occurs in the variable component and no local contrast occurs either. It also cannot explain anticipatory contrast, which appears to be the major component of molar contrast.

Reinforcer Habituation/Satiation

A second *artifactual* interpretation of behavioral contrast is that it derives from differences in the effectiveness of the reinforcers during the contrast versus baseline phases of training. McSweeney and Weatherly (1998) argued that reinforcers lose effectiveness as a function of the frequency of reinforcement in an experimental session, owing to habituation of the reinforcer's value. Because the typical contrast experiment compares a baseline phase (with VI schedules in both components of a multiple schedule) with a contrast phase (with a multiple VI EXT schedule), this entails that fewer reinforcers/session occur during the contrast phase, so that the reinforcers associated with the unchanged VI schedule should be more effective and, therefore, produce a higher response rate. While McSweeney and Weatherly argued that this *habituation* effect was not the same as simple satiation, either account poses the same difficulty for interpreting contrast. That is, most contrast experiments change reinforcement rate in only one of the components, which necessarily confounds the effect of changes in relative reinforcement rate with the rate of reinforcer delivery per unit of session time. For example, when a multiple VI 1-min VI-min is changed to VI 1-min EXT, the rate of reinforcers over the entire session in the baseline phase is twice that during the contrast phase. There is, in fact, no simple way to avoid this confound, but its importance depends critically on parameters of habituation/satiation, which presently are unknown. It is possible that variations in reinforcer effectiveness play a much larger role in some experiments than in others—for example, when high rates of reinforcement are used, or when the experimental session terminates after a fixed time, rather than after a fixed number of reinforcers.

The possibility that a significant portion of experimental results in the contrast literature may be due to satiation/habituation effects is disturbing and warrants serious assessment. It is possible, for example, that the confound is differentially important for different types of subjects (e.g., rats vs. pigeons). One way to document the role of that

confound is to measure concurrently the size of the contrast effect and the absolute response rates continuously over the course of an experimental session, for both the baseline and the contrast phases of the experiment. Similarly, variations in the amount or frequency of reinforcement should be expected to affect the amount of contrast, because any habituation effect should be larger the greater the total amount of reinforcement. Data relevant to the latter type of assessment are available but conflicting. Speelman and Gollub (1974) reported that the amount of contrast was greater with leaner reinforcement schedules, an inverse relationship that appears inconsistent with the habituation/satiation account. White and Cameron (2000) have replicated this finding. However, McSweeney, Dougan, Higa, and Farmer (1986) reported larger contrast effects with higher rates of reinforcement, especially when very high reinforcement rates (240/h) were employed.

Even assuming that changes in reinforcer effectiveness occur as a function of the number of reinforcer presentations within an experimental session, such effects play no role in contrast procedures in which the total number of reinforcers per unit of session time is held constant. In the A–X, B–Y anticipatory contrast procedure described earlier, for example, the independent variable is the location of the various schedules in the component sequence, whereas the total rate of reinforcement over the entire session is held constant (also see Williams, 1976). Given that anticipatory contrast appears to be a major component of steady-state molar contrast (Williams, 1981; Williams & Wixted, 1986), such effects of the sequential arrangement of schedules require an explanation in terms of the comparison of the reinforcement values for the various schedules in the sequence.

Response-Independent Conditioned Reinforcement

Yet a third *procedural* explanation of anticipatory contrast is that a rich following schedule may suppress behavior in the target component because the stimulus for the following schedule is a conditioned reinforcer that is delivered independently of responding (because transition between components is determined entirely by time). Thus, just as response-independent primary reinforcers suppress operant behavior, so also should conditioned reinforcers (cf. Marr & Zeiler, 1974). Williams (1988a) tested this possibility by evaluating the role of the contingency for transition between the A and B target components and their respective following schedules. The target components terminated either as a function of a fixed time (the usual case) or as a function of the first response after the time requirement had elapsed (an FI requirement). The size of the anticipatory contrast was only slightly diminished by the FI requirement. A similar comparison was reported by Nevin et al. (1987), who found that there was a somewhat larger reduction in anticipatory contrast when the FI requirement was used but that robust anticipatory contrast occurred nonetheless.

In summary, the various explanations of contrast in terms of *procedural confounds* are important in sensitizing investigators to possible experimental artifacts that often occur in contrast experiments, but none provides a general explanation of contrast. I turn now to accounts that depend on more general processes of greater theoretical interest.

Frustration/Arousal/Release From Inhibition

As was noted above, one early prominent account of contrast emphasized its kinship with frustration theory (Amsel, 1971), which assumed that nonreinforcement of a previously reinforced response has drive-like properties that energize behavior in the experimental situation. Malone (1976) argued that contrast is a form of Pavlovian induction, owing to the release from inhibition controlled by the preceding inhibitory conditioned stimulus (CS). Such accounts do have some predictive validity, but only with respect to local contrast, not molar steady-state contrast. But given that local contrast may persist and is a substantial component of molar contrast in some situations, the arousal effects of *frustration* or *release from inhibition* can possibly account for a substantial number of experimental reports of contrast, especially when only the average rate of responding throughout a component is reported. But it is essential to note that the degree of contrast can be inversely related to the amount of nonreinforced responding, as in Williams (1976; see Figure 2, above), and that contrast occurs when no nonreinforced responding occurs in the variable component of the multiple schedule (e.g., when time-out is used).

The Behavioral Reallocation Hypothesis

The operant response is not the only behavior that occurs in an experimental chamber. According to Herrnstein's (1970) analysis of single-response procedures, any operant training procedure necessarily involves the dynamics of choice, between the operant response and other behaviors that are not being measured. A variation of this perspective has been considered by some to provide an explanation of behavioral contrast (Hinson & Staddon, 1978; McLean & White, 1983; Staddon, 1982). According to this account, the typical multiple schedule is actually a multiple schedule with concurrent schedules in each component. The primary reinforcement schedule is assigned to the measured response in each component; the secondary schedule is for the unmeasured *extraneous* behaviors that are present during both components of the multiple schedule. Extraneous responses controlled by the secondary schedule in a component thus compete with the operant behavior that is measured. When a multiple VI VI schedule is changed to a multiple VI EXT, the extraneous behavior controlled by the secondary schedule is free to occur at a high rate when the schedule for the operant response is EXT. The critical assumption is that the value of the unmeasured reinforcers for that extraneous behavior (e.g., preening) is thereby reduced, owing to transitory satiation. The competition from the extraneous behavior when the sched-

ule returns to the unchanged VI component is therefore reduced, so that the operant behavior controlled by the unchanged primary schedule increases in rate.

Despite some striking evidence supporting the behavioral reallocation hypothesis (Hinson & Staddon, 1978) and the development of quantitative models that seem to have some degree of predictive power (McLean, 1995), its potential to provide a general explanation of contrast is limited by its dependence on behavioral competition as its underlying causal mechanism. That is, the reinforcement value of the extraneous behavior is assumed to be an inverse function of its rate of occurrence, which is limited by competition from the operant behavior. But contrast is not a function of changes in the level of behavior in the altered component but, rather, of the change in the rate of reinforcement in the altered component. Contrast occurs readily when a multiple VI VT schedule is changed to a multiple VI EXT, even though the extraneous behavior is free to occur at any time during the VT component. Conversely, contrast does not occur (at least generally) when a multiple VI VI is changed to a multiple VI signaled VI (Williams, 1980). The latter case is especially compelling because the rate of operant behavior controlled by a signaled VI schedule is essentially similar to that occurring during extinction and, therefore, similar in the degree of competition with the extraneous behaviors.

The behavioral reallocation hypothesis also implies that contrast should always be greatest at the beginning of the unchanged component, because that is when the satiation of the reinforcers from extraneous behavior is at its maximum. But this prediction is challenged by the fact that local contrast is transitory and dependent on the similarity of the discriminative stimuli. Moreover, anticipatory contrast seems directly contrary to the dynamics invoked by the behavioral allocation hypothesis.

Additivity Theory

Additivity theory explains contrast as the result of responses generated by the Pavlovian contingency between the component stimuli and the reinforcement being added to the operant response rate maintained by the response contingency (Keller, 1974; Rachlin, 1973). Three types of evidence have been adduced for this theoretical interpretation: (1) Behavioral contrast more readily occurs when the component stimuli are located on the response manipulandum, (2) the occurrence of contrast is paralleled by the occurrence of elicited responding in multiple schedules using entirely response-independent schedules of reinforcement, and (3) when a *signal-key* procedure is used, in which the stimuli cuing the different components of a multiple schedule are presented on one response key, while the operant response requirement during both components is located on a second response key, signal-elicited pecks are affected by reinforcement in the alternative component, whereas responses to the operant key are not.

At the time additivity theory was developed, the evidence in its favor seemed compelling. Perhaps as a result,

many current textbooks of animal learning still include *additivity theory* as a viable theoretical explanation. In retrospect, however, all aspects of the evidence failed to withstand close scrutiny. Contrast does readily occur when the discriminative stimuli are spatially separate from the response location (e.g., Bradshaw, Szabadi, & Bevan, 1978; Gutman, Sutterer, & Brush, 1975). The finding that it occurs more readily when the stimuli are on the response location may reflect only the role of improved stimulus control, given that it has long been known that spatial separation of the stimulus and the response often can have severely deleterious effects on discrimination learning (e.g., McCleary & Harlow, 1954).

The parallels between elicited responses when response-independent reinforcement schedules are used and the occurrence of contrast is also likely dependent on differences in stimulus control. During the typical contrast experiment using pigeons pecking response keys, stimulus control by the keylights is established during the baseline training when the response-contingent reinforcement occurs during both components of the multiple schedule. Although discrimination training may sharpen the degree of stimulus control, which may increase response rate to some extent (Lyons & Thomas, 1967), it does not produce stimulus control *de novo*. By comparison, in multiple VT VT schedules, there is no reason for the pigeons to attend to the response key during the baseline training, because it provides no information and responding to it is not required for food delivery. But then, with the change to multiple VT EXT, the keylight acquires signal value for the first time, and pigeons do indeed peck stimuli that signal food. However, there is no necessary reason to assume that a comparable change in signal value occurs when response-dependent schedules are used, where the keylight stimuli exert behavioral control even during the baseline training.

A similar problem arises in the interpretation of the results from the signal key procedure. During baseline training, nondifferential reinforcement occurs during both components of the schedule for pecking the *operant key*, so that the signal key provides no information. Then, when a discrimination contingency is imposed for the operant key, the stimuli on the signal key acquire stimulus control for the first time. This creates a new response unit of *look at signal, peck operant*, whereas the baseline response unit was simply *peck operant*. Not surprisingly, contrast may fail to occur to the operant key because the change in response unit works in the opposite direction. Evidence for this interpretation was provided by Williams and Heyneman (1981), who demonstrated that contrast on the operant key did indeed occur when stimulus control to the signal key was established during the baseline training, so that the response unit was not disrupted by the advent of differential reinforcement in the two components of the multiple schedule. Williams and Heyneman also demonstrated that a substantial portion of signal key pecking was controlled not by the signal-food contingency, but by adventitious reinforcement of signal key pecking by reinforcement ob-

tained from operant responding (see also White, 1982). Further evidence against additivity theory is reviewed by Williams (1983).

Relative Reinforcement Rate and the Matching Law

As was noted in the introduction, contrast effects were encompassed within Herrnstein's (1970) relative law of effect, which attempted to explain all operant behavior in terms of the concept of relative rate of reinforcement. That is, a given rate of reinforcement produced a behavioral output not on the basis of its absolute value, but instead on the basis of its absolute value relative to the context of reinforcement in which it occurred. Accordingly, the only difference between multiple schedules used to study behavioral contrast and concurrent schedules used to study the matching law was the method by which the context of reinforcement was calculated. In concurrent schedules, the determinants of choice behavior were only the reinforcement schedules immediately available, because the reinforcers from other sources canceled in the matching equation; for response rate in multiple schedules, the context includes reinforcement in temporally proximal time periods, and these temporally proximal reinforcers could be different for the different components of the multiple schedule.

Although Herrnstein (1970) provided a comprehensive framework for a general description of operant behavior, the subsequent theoretical development of the matching law undercuts the generality of that description. Thus, rather than choice behavior being controlled directly by relative rate of reinforcement, matching was due to the dynamics of *melioration*, the process by which the subject in a choice situation equalizes the local rate of reward for each of the competing alternatives in that situation (see Williams, 1988c, for a description of the evolution of melioration as a theoretical account). The process of melioration is orthogonal to the concept of context of reinforcement, which implies that the dynamics of choice behavior provide no basis for explaining contrast effects in multiple schedules in which the behaviors in the temporally alternating components are not in direct competition. This does not necessarily mean that behavioral contrast and matching require different explanatory frameworks, especially given that the melioration theory of matching has been strongly challenged by several different types of evidence (see Williams, 1994b, for a discussion; see also Gallistel & Gibbon, 2000, for a very different account of matching).

One specific challenge that is directly related to the general issue of the relation between multiple and concurrent schedules is the similarity in the effects of alternative reinforcement in a concurrent schedule when it is contingent on a second response versus delivered independently of responding (Rachlin & Baum, 1972). Such results suggest that the *context of reinforcement*, quite apart from the dynamics of melioration, determines the level of operant behavior to a given response alternative in a concurrent schedule. Perhaps, therefore, the concept of relative rate of

reinforcement really does provide an adequate description of the conditions under which contrast occurs. But even at a descriptive level, the concept of relative rate of reinforcement must be refined to account for the fact that the reinforcement conditions defining the context of reinforcement have different impacts on behavior, depending on their temporal location (Williams & Wixted, 1986). There is no obvious rationale for why the reinforcement conditions following a period of target response availability should be more important than the reinforcement conditions preceding the target response. Such differential effects suggest that the general concept of context of reinforcement needs to be reduced to more fundamental behavioral mechanisms. I will return to this issue later, when contrast effects are related to more general contingency effects.

CONTRAST AND VALUE

The general failure of extant theories of contrast to explain the major empirical properties of contrast suggests the need to return to the basic idea of contrast to better define the dimensions of an adequate conceptual framework. The essence of the concept of contrast is that the relative value of a stimulus, not its absolute value, determines its behavioral effects. In the standard behavioral contrast experiment, this implies that the fixed rate of reinforcement associated with the constant component has a higher value when alternated with extinction than when alternated with a higher rate of reinforcement. An increased response rate in the constant component is the result, on the basis of the assumption that response rate is correlated with stimulus value. But is this assumption justified? Early interpretations of contrast, such as Amsel (1971) and Terrace (1966), viewed contrast as a product of nonreinforced responding, and such effects could reflect generalized arousal, rather than a change in the value of the reinforcement schedule. Although this *frustration/inhibition* interpretation of contrast is contradicted by various experimental findings (e.g., Williams, 1976), the assumption that contrast with respect to response rate reflects relative value has been more an assumption than a proven fact. Indeed, the *mechanistic* accounts of contrast considered in the preceding section are predicated on the assumption that value is an unnecessary construct and that the changes in response rate in contrast procedure can be accounted for by known determinants of response strength. But given that such accounts have generally failed, it is worthwhile to consider what, if any, explanatory function the concept of relative value provides.

Any assessment of the relation between response rate and stimulus value requires measures of stimulus value other than response rate. Two different measures have been used in previous studies: preference in probe tests and resistance to change. Preference was the measure of value used by Bloomfield and Russell (1970). In their procedure, S+ and S- stimuli alternated on one response key in 1-min intervals for blocks of 10 min. On the second key, a different keylight, S3, correlated with the same schedule as the S+, was presented continuously for 10-min blocks,

which alternated with the 10-min blocks of the S+/S- discrimination training. Contrast occurred in the component with the alternating S+ and S-, and there was a near-perfect correlation between the size of the contrast effect and preference for the S+ over S3 in probe preference tests. Thus, Bloomfield and Russell concluded that the occurrence of contrast with respect to response rate was determined by changes in the value of the reinforcer schedule associated with the S+.

A very different relation between preference and response rate in contrast procedures was reported by Williams (1991, 1992c) using the A-X, B-Y anticipatory contrast procedure, which produced an inverse relation between preference and response rate. But as was discussed above, this inverse relation is seemingly the result of the Pavlovian contingencies embedded in the anticipatory contrast procedure. If Pavlovian associations and anticipatory contrast are competing sources of stimulus value, only when their separate influences are dissociated is it possible to define the relation between contrast and value in a clear fashion. Thus, the results from Williams and McDevitt (2001) that were described earlier are especially important because they demonstrate such a dissociation. When chain schedules were used in the target components of the A-X, B-Y procedure, preference and response rate were strongly positively correlated. That is, both preference and response rate were in favor of the initial-link stimulus that led to the richer following schedule, whereas both measures were in favor of the terminal-link stimulus that led to extinction. Thus, the tentative conclusion, using preference as a second measure of stimulus value, is that contrast with respect to response rate does reflect an increase in stimulus value, consistent with common intuition.

A more ambiguous conclusion has come from studies using resistance to change as the measure of stimulus value. Resistance to change is measured by the rate of change in response rate when some type of disrupter is presented (e.g., free food), rather than by response rate per se. In Nevin (1992), pigeons were trained on a multiple VI VI schedule in which the constant component was always 60 reinforcers/h. Across conditions, the alternated component arranged 300 or 10 reinforcers per hour. Response rates were higher in the constant component when the alternating component had fewer reinforcers. Most important, resistance to change for the constant component was also greater when the alternating schedule had fewer reinforcers, indicating a positive relation between contrast and value.

This conclusion was challenged by the results of Nevin and Grace (1999), who concluded that resistance to change in the constant component was unaffected by relative rate of reinforcement and whether contrast occurred. They also argued that the results of Nevin (1992) should be discounted, on the basis of a reanalysis of its data. The major procedural difference between the two studies was the method by which the contrast effects were established. In Nevin, a single constant schedule was alternated with different schedules for 1-month periods, and resistance to change tests were conducted at the end of each period. In Nevin

and Grace, two different target schedules with equal reinforcement schedules were used, each on a separate response key. One of the target components was alternated with a leaner reinforcement schedule for one half of the session; then, the other target component was alternated with a richer reinforcement schedule for the remaining half of the session. Resistance to change assessments were conducted after behavior for both target components had stabilized. Resistance to change was similar for the two target components when the resistance-to-change manipulation was prefeeding prior to the testing session. When assessed by extinction, resistance to change was greater for the target component alternated with extinction, but Nevin and Grace discounted this difference as being due to the role of generalization decrement as a separate determinant of resistance to extinction.

In addition to their resistance-to-change tests, Nevin and Grace (1999) presented their two target components together on probe trials and found a small but statistically nonsignificant difference in favor of the target component alternated with the leaner reinforcement schedule. As was described above, several studies using the A–X, B–Y procedure have shown that preference was strongly in favor of the target component (B) that leads to the richer following schedule. It is important to recognize that the procedure used by Nevin and Grace is, in fact, a variation of the A–X, B–Y procedure. Whereas that procedure usually has randomly interspersed A–X and B–Y pairs within the session, in their procedure the A–X and B–Y presentations were blocked in one-half session units. This may or may not attenuate the Pavlovian contingencies between the target components and their respective following schedules, given that we do not know the time frame over which contingencies were calculated. If some degree of Pavlovian association did occur in the procedure of Nevin and Grace, the conflict in results between Nevin (1992) and Nevin and Grace could be due to the presence of that Pavlovian association in the latter case, but not in the earlier study.

CONTRAST VERSUS CONTINGENCY EFFECTS

The contingency between the stimulus and the reinforcer in Pavlovian conditioning and between the response and the reinforcer in operant situations has been varied by presenting unpaired reinforcers in addition to those paired with the CS or operant response. The larger the number of unpaired reinforcers, the weaker the degree of conditioning, although a substantial debate is ongoing about whether such effects reflect true learning effects versus effects on performance. It should be apparent that contrast procedures share a basic kinship with contingency experiments, in that both demonstrate changes in the level of conditioned responding owing to variations in the context of reinforcement. The major difference is that contingency experiments present the additional reinforcers in the presence of the same conditioning context that is present for paired

reinforcers, whereas contrast experiments present the additional reinforcers in temporally adjacent periods cued by different stimuli. But this difference is surely a matter of degree, given that contrast effects are larger with shorter component durations (Williams, 1989a) and that much of the same experimental context is shared by both components of a multiple schedule. Moreover, one variation of the contingency experiment is to signal the unpaired reinforcers with a second stimulus. Short signals seem to have little effect, but signals 10–15 sec in duration substantially decrease the reduction in conditioning produced by unpaired reinforcers that are unpaired (Williams, 1989b, 1994a). The presentation of signaled unpaired reinforcers is even more similar to contrast procedures, which suggests that a common explanation is applicable to both. That is, contrast is a contingency effect that is attenuated by having the reinforcers unpaired with the target behavior being signaled by a different stimulus.

This possible insight unfortunately does not advance the theoretical analysis of contrast, because contingency effects themselves continue to be subject to theoretical controversy. The most prominent explanation has been in terms of *context blocking* (Rescorla & Durlach, 1987), but that account has been challenged by *comparator models* (Gibbon & Balsam, 1981; Miller & Matzel, 1988), which assume a comparison process much like the intuitive notion of contrast itself. Nevertheless, an appreciation of the conceptual similarity between contrast and contingency suggests that additional empirical parallels between the two empirical domains should occur. For example, using multiple schedules of response-independent reinforcement, Farley (1980) demonstrated that higher response rates occurred when the target stimulus was followed by periods of extinction than when preceded by periods of extinction, although either location of an extinction component engendered elicited pecking in its own right. It should be noted, however, that maintained behavior was studied, rather than initial acquisition. From the converse perspective, the postconditioning *revaluation* procedures (e.g., Blaisdell, Gunther, & Miller, 1999) that have supported the comparator theory might also occur in contrast procedures. For example, manipulation of the value of the variable component of a multiple schedule outside the multiple-schedule training procedure might be expected to change the behavior in the target component even though the target component is never presented in conjunction with the revalued component. As yet, such an experiment has not been reported.

Of special interest to the present discussion is the possibility that the explanatory framework for contingency effects may enlighten the mechanistic basis of contrast. For example, when a multiple VI VI schedule is changed to multiple VI EXT, the concept of context blocking entails that the common stimulus properties shared by responding in the two components of a multiple schedule during baseline training should lose associative value, which should accrue to the stimuli unique to the unchanged VI. This

provides a straightforward explanation of the simplest type of contrast effect but unfortunately cannot encompass many of the more detailed findings about contrast. Context blocking provides no basis for why molar contrast consists mainly of anticipatory contrast or for why contrast generally does not occur when the schedule is changed from multiple VI VI to a multiple VI signaled VI, even though similar experimental procedures have supported context blocking accounts of contingency effects in Pavlovian conditioning (Durlach, 1983). Context blocking also fails to provide an explanation for why contrast effects are larger with shorter component durations.

Comparator models of conditioning appear more successful in accounting for contrast effects, but only because the concept of comparison between reinforcement rates during different stimulus conditions is central to both. There are, nevertheless, several features of contrast that challenge whether contrast is simple a special case of comparator models. Most obvious, again, is that there is no basis for why anticipatory contrast is the dominant effect in steady-state contrast procedures. More generally, it is not clear how the comparator term should be defined in a contrast procedure. In simple Pavlovian conditioning, the comparator is the rate of reinforcement associated with the context in which the CS presentations occur (although the results of Farley, 1980, suggest that the definition of the comparator stimulus may involve a temporal asymmetry with respect to the CS-US pairing). Problematic for such an idea is the finding that changing a multiple VI VI to a multiple VI signaled VI does not produce contrast, whereas changing a multiple VT VT to a multiple VT signaled VT does produce elicited behavior. This apparently major difference between operant and Pavlovian conditioning must be understood before a simple translation of explanatory concepts from Pavlovian conditioning to contrast effects in operant procedures is likely to be fruitful. There is, however, one provocative similarity between comparator theory and the paradox of anticipatory contrast described earlier. For anticipatory contrast to occur, the target components must predict their following components, but the *association* underlying this predictiveness is apparently different from a simple Pavlovian association. Different types of associative relations are also involved in comparator theory, since the CS-US association is compared with the context-US association, but in addition the context and the CS must themselves be associated, but without the excitatory/inhibitory dynamics of one transferring to the other. The latter type of association governs the expression of the behavior as a performance rule. But there remain important differences. Theories of contrast are silent with respect to the learning-performance distinction and interpret the effects of the context of reinforcement in terms of changes in the value of the reinforcement schedule. Whether this distinction is conceptually meaningful or merely semantic remains to be seen.

The purpose of this review has been to counter the widely accepted view that the study of behavioral contrast is a moribund enterprise. Because changes in response rate in

contrast procedures can be produced by any of several different mechanisms, many observers have regarded the phenomenon to be sufficiently chaotic to not warrant the effort necessary to sort out the critical differences. No doubt there are many difficult issues that remain to be resolved. But there seems little doubt that contrast is a pervasive aspect of reinforcement value, so that any general theory of reinforcement must address its often paradoxical features. The phenomenon of anticipatory contrast in itself begs for a deeper understanding. Whether there is sufficient interest to generate the research necessary to accomplish that understanding is unclear, and it, like many interesting findings in the conditioning literature, may be destined to be added to the historical scrapheap of ideas abandoned prematurely.

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