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ANOTHER LOOK AT CONTRAST IN MULTIPLE SCHEDULES

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Recent research on multiple schedule interactions is reviewed. Contrary to formulations that view contrast as the result of elicited behavior controlled by the stimulus-reinforcer contingency (e.g., additivity theory), the major controlling variable is the relative rate of reinforcement, which cannot be reduced to some combination of stimulus-reinforcer and response-reinforcer effects. Other recent theoretical formulations are also reviewed and all are found to face serious counterevidence. The best description of the available data continues to be in terms of the "context of reinforcement," but Herrnstein's (1970) formulation of the basis of such context effects appears to be inadequate. An alternative conception is provided by Catania's concept of "inhibition by reinforcement," by which rate of responding is inversely related to the average rate of reinforcement in the situation. Such a conception is related to Gibbon's recent scalar-expectancy account of autoshaping and Fantino's delay-reduction model of conditioned reinforcement, suggesting that a common set of principles determines several diverse conditioning phenomena. However, the empirical status of such a description remains uncertain, because recent evidence shows that schedule interactions are temporally asymmetric, depending primarily upon the conditions of reinforcement that follow a schedule component.

Key words: multiple schedules, relative rate of reinforcement, schedule interactions, matching, contrast, additivity theory, law of effect, behavioral competition theory, inhibition by reinforcement

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I. INTRODUCTION

When two responses are maintained by separate schedules of reinforcement, and the density of reinforcement for one of the responses is increased, the rate of the other response, associated with the unchanged schedule, typically decreases. Conversely, when the reinforcement density of the first schedule is decreased, the rate of the second response increases. These interactions between schedules of reinforcement, usually labeled "contrast," occur when the two schedules are simultaneously available (concurrent schedules: Herrnstein, 1970) and when they are successively alternated (multiple schedules: Reynolds, 1961a).

The present paper reviews the status of interactions in multiple schedules. The review is restricted to that smaller domain because it is uncertain whether interactions in multiple and concurrent schedules occur for the same reasons and because research on each schedule has become so massive that a combined review of both would be too large an undertaking. Equally important, multiple schedules remove a degree of freedom for the theoretical interpretation of contrast, since direct competition between the response alternatives cannot be the mediator of contrast when the alternatives are never simultaneously available. Consequently, contrast effects in multiple schedules should reflect the relativistic effect of reinforcement at its most fundamental level.

Contrast in multiple schedules is perhaps the most heavily investigated topic in free-operant research in the past 20 years. However, interest in the phenomenon has substantially declined in recent years, in large part because contrast now appears to be due to several different effects, all of which may be operative in any particular situation, so that researchers despair over sorting out the controlling variables. This is not to say that there is no consensus about the variable that is most important. At least judging from the treatment of the topic in recent learning textbooks, contrast is primarily explained by "additivity theory," which views contrast as the addition of "elicited" behavior, controlled by the stimulus-reinforcer contingencies (e.g., Catania, 1979; Rachlin, 1976; Schwartz, 1978b; but see Fantino & Logan, 1979, for a notable exception).

I believe the current views on the status of contrast to be fundamentally incorrect. I will argue not only that additivity theory is not the correct explanation for any important aspect of contrast but also that contrast remains an important crucible for testing the most basic issues in the study of operant behavior. It is true that several different effects have been given the common label of contrast, so that dissociating the different controlling variables is often a difficult task. But it is also true, I believe, that a single dominant variable underlies contrast, at least in steady-state procedures, and defining that variable is of fundamental importance for specifying the independent variables that control all operant behavior. To foreshadow the discussion, the issue is the status of relative rate of reinforcement. Is it a primordial variable that controls all behavior (cf. Herrnstein, 1970) or is it reducible to some more molecular mechanism, the understanding of which should be the key to the proper interpretation of a major segment of free-operant research?

II. MAJOR EMPIRICAL FINDINGS

A. The Independent Variable: Relative Reinforcement Rate or Response Suppression

In a typical contrast procedure, a multiple VI VI is changed to a multiple VI EXT. The result is that both responding and reinforce-

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ment in the altered component (VI→EXT) are decreased. Early discussions of contrast were concerned primarily with dissociating the two variables, in order to specify which was the cause of the contrast effect that normally was obtained in the alternative component. Since previous reviews have dealt extensively with this issue (de Villiers, 1977; Freeman, 1971b; Hearst & Jenkins, 1974; Schwartz & Gamzu, 1977), only the highlights of the empirical literature regarding this issue will be described.

The major conclusion reached in previous reviews of contrast is that the relative rate of reinforcement is the controlling variable, at least to a first approximation. Figure 1 (taken from Nevin, 1973) provides an illustration of the evidence supporting this conclusion, as it shows how response rates maintained by a constant VI schedule are affected by changes in the relative rate of reinforcement associated with the VI, independent of the type of schedule in the alternative component where the absolute reinforcement rates were varied. Since the different types of schedules produced very different response rates, any interpretation of contrast that relies on changes in the rate of responding in the alternative component should predict major differences across the various experiments that are shown. Instead, the functions are generally similar, showing that the actual rate of responding in the alternative component is largely irrelevant.

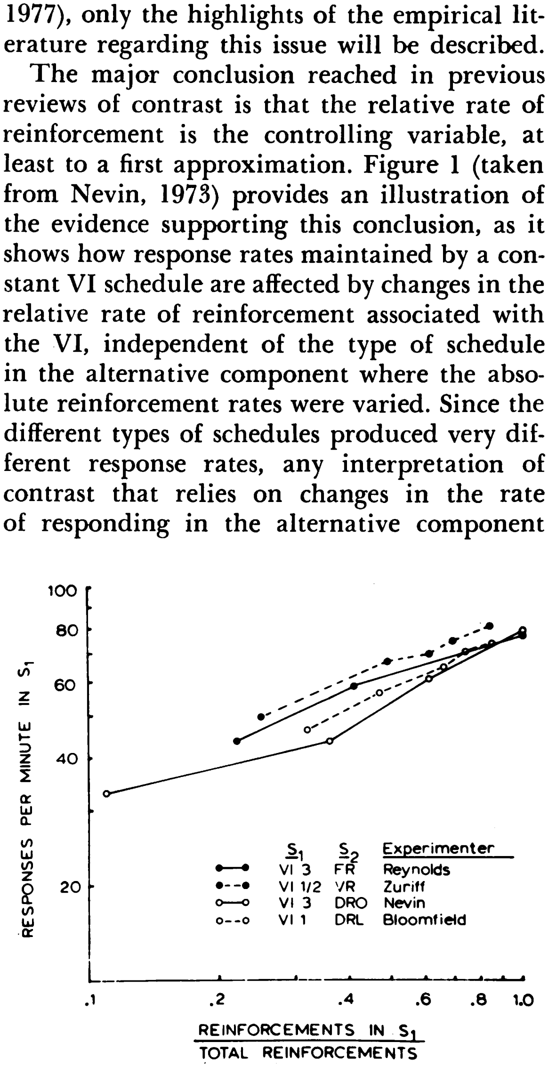

Fig. 1. Data taken from Nevin (1973) showing the results of several contrast experiments in which the schedule in the altered component was different. The response rates shown are from the constant VI components. The relative frequency of reinforcement varied as a consequence of variations in the schedule value in the alternated component. The results were taken from Zuriff (1970), Bloomfield (1967), Reynolds (1961b), and Nevin (1968). Note that both the abscissa and ordinate are in logarithmic units.

But the conclusion that relative rate of reinforcement is the only variable controlling contrast can be challenged on several grounds. One such challenge comes from studies that have reported contrast when a multiple VI VI is changed to a multiple VI DRL without changes in the corresponding rates of reinforcement (Terrace, 1968; Weisman, 1969). Unfortunately, such results are now difficult to interpret, because a more recent study (Boakes, Halliday, & Mole, 1976) has provided evidence that such effects were either an artifact of a rising baseline or were due to uncontrolled variations in the local rate of reinforcement.

A similar challenge comes from studies that report contrast when punishment is added in one component of a multiple VI VI (Brethower & Reynolds, 1962; Terrace, 1968). Unlike the results with the multiple VI DRL, here there seems to be little question about the reliability of the finding, as the basic effect has been replicated (Farley & Fantino, Note 1). However, a contrast effect due to punishment is evidence against relative rate of reinforcement as the controlling variable only if punishment and positive reinforcement are assumed to be functionally independent. Such an assumption is dubious, given recent findings that the addition of shock to an appetitive situation is functionally equivalent to the removal of food (de Villiers, 1980; Farley, 1980b; Farley & Fantino, 1978). If the addition of punishment is conceived as the subtraction of food, then the finding of contrast due to the addition of punishment does not provide critical evidence.

The one situation that has provided strong support for the response suppression interpretation is when a multiple VI VI schedule is changed to a multiple VI signaled VI schedule. The result of that procedure is that responding in the signaled component generally occurs only after the signal has been presented, but the obtained frequency of reinforcement is unaffected. Since contrast has been reported in several studies that have used this procedure (Brownstein & Hughes, 1970; Marcucella, 1976; Wilkie, 1973, 1977), the apparent implication is that response suppression is sufficient to produce contrast, at least under some circumstances.

However, substantial evidence against reductions in response rate as a critical variable has been provided by studies in which multiple VI VI has been changed to multiple VI VT (VT refers to a variable-time schedule that is similar to a VI except that reinforcer delivery is independent of responding). In these studies (cf. Halliday & Boakes, 1974) responding in the VT component decreases, usually to a near-zero level, and yet no contrast occurs in the unchanged VI with which the VT is alternated. Partly in response to these data, Terrace (1972) argued that the critical variable was not a reduction in responding per se, but rather an "active inhibition" of responding. More recently, a related argument has been sponsored by Marcucella (1976) and Wilkie (1977), who proposed that the critical variable was the occurrence of discriminated periods of nonreinforcement. In support of this argument, Wilkie (1977) changed a multiple VI VI to a multiple VI FI, and a multiple VI VT to a multiple VI FT, so that the FI and FT schedules provided equivalent average reinforcement rates to the VI and VT schedules that preceded them. The result in both cases was a substantial contrast effect in the unchanged VI component.

Although the evidence in favor of discriminated periods of nonreinforcement as the critical variable appears to be substantial, Williams (1976a) has provided strong evidence that it is not the controlling variable. Pigeons were initially trained with a multiple VI 90-sec VI 90-sec schedule with alternating 90-sec components. One component was then changed to a variant of FI, such that one reinforcer was delivered during each 90-sec component. Thus, the average rate of reinforcement was unchanged. The variable of interest was the location of the reinforcer within the FI component. In one condition it occurred early (5 sec after the start of the component), and in a second it occurred near the end (80 sec after the start). After the reinforcer was obtained, the remainder of the component was always associated with extinction. The results were that the FI 5-sec condition produced the greatest reduction in responding during the FI component but no contrast in the unchanged VI component. Instead, a substantial response suppression occurred in the unchanged VI. On the other hand, the FI 80-sec condition produced only a small amount of suppression during the FI component but did cause a contrast effect in the unchanged VI (a result similar to Wilkie, 1977). This dissociation of the degree of response suppression from the degree of contrast thus provides strong evidence against periods of discriminated nonreinforcement as the controlling variable.

Further evidence against response suppression comes from the recognition that contrast does not always occur when signaled reinforcement is employed (Griffin & Stewart, 1977; Gutman & Fenner, 1982; Williams, 1980). Moreover, there is reason to believe that when it does occur, it is not the same effect as contrast caused by changes in relative rate of reinforcement. The evidence for the latter claim comes from Williams (1980), who compared the response rates of multiple VI VI, multiple VI signaled VI, and multiple VI EXT under different component durations. The magnitude of contrast with the multiple VI EXT was greater with shorter components so that a comparable effect should have been obtained with the multiple VI signaled VI if similar mechanisms were involved. However, shorter components did not increase response rate in the unaltered VI component of the multiple VI signaled VI, and in fact the rates obtained with that schedule were nearly identical to those with the multiple VI VI for all component durations. Thus, contrast is not a universal finding with the signaled reinforcement procedure, and it apparently does not follow one of the major functional relations that determines contrast due to changes in relative rate of reinforcement.

The conclusion from the procedures just discussed is that contrast is primarily a function of changes in relative reinforcement frequency. But this conclusion should be tempered by the reports of contrast with the signaled reinforcement procedure. As argued by Williams (1980), such demonstrations imply that there is probably more than one determinant of contrast, at least under some circumstances. One potentially important variable, in addition to relative reinforcement rate, is the effect of a discrimination requirement on response topography. The typical contrast experiment involves nondifferential reinforcement in the baseline (multiple VI VI), which is changed to differential reinforcement in the contrast phase (multiple VI EXT, or multiple VI signaled VI). The result may be an increase in the efficiency of the response unit, since shifts from nondifferential to differential reinforcement have been shown previously to sharpen the degree of stimulus control (e.g., Lyons & Thomas, 1967). It seems likely that an increase in control by the key stimulus would be accompanied by a sharper localization of pecks on the response key, with the result being an increase in measured response rate. Such an interpretation is speculative, but some such account seems necessary to explain the conflicting results that have been reported (see Bloomfield, 1966, for a similar interpretation).

B. QUANTITATIVE FORMULAE FOR EFFECTS OF RELATIVE RATE OF REINFORCEMENT

The preceding discussion provides evidence that relative rate of reinforcement is the primary determinant of interactions in multiple schedules. Consequently, a better specification of the effects of relative rate of reinforcement should help delineate the underlying principles. Lander and Irwin (1968) proposed Equation 1, which is a simple power function relating reinforcement ratios to response ratios, where B_1 represents response rate in Component 1, B_2 represents response rate in Component 2, and R_1 and R_2 represent the corresponding reinforcement rates:

$$\frac{B_1}{B_2} = \left(\frac{R_1}{R_2}\right)^a . \tag{1}$$

Herrnstein (1970) proposed Equation 2 as an alternative description, derived from his description of response rates in concurrent and simple VI schedules. The terms of Equation 2 correspond to those of Equation 1 except for the addition of R_o, which represents the reinforcement in the situation other than that scheduled in the separate components of the multiple schedule (e.g., that not under direct experimenter control):

$$\frac{B_1}{B_2} = \frac{\dfrac{R_1}{R_1 + mR_2 + R_o}}{\dfrac{R_2}{R_2 + mR_1 + R_o}} . \tag{2}$$

The major difference between the two equations is that Equation 1 captures the degree of interaction between the components of the schedule by the exponent *a*, whereas Equation 2 captures the degree of interaction by the parameter *m*, which is assumed to vary between 0 and 1 as a function of the duration of the schedule components. The relative merits of the two equations have not been rigorously tested since both Lander and Irwin (1968) and Herrnstein (1970) have reported that their functions describe their data at a qualitative level, but neither reported the quantitative characteristics of the fit provided by the functions.

Nevin (1974a) has argued that the two equations can be distinguished by adding an extra source of reinforcement to the situation. He presented a multiple VI VI concurrently with a FI schedule on the other key. There is nothing in Equation 1 that predicts that the rate of additional reinforcement should affect the interaction between the components of the multiple schedule, so accordingly the fit of Equation 1 should be independent of the additional reinforcement. On the other hand, Equation 2 captures the effect of the additional reinforcement by the parameter R_o, with the result that Equation 2 predicts that the relative rate of responding should vary with the amount of the additional reinforcement. That is, responding in both components should decrease as R_o is increased, but the rate of decrease should be greater for the component with the lower reinforcement rate. The results were that the relative rate of responding in the multiple VI VI did increase as R_o was increased, thus supporting Equation 2.

But relative response rates in a multiple schedule have not always shown this sensitivity to additional reinforcement arranged independently of the multiple schedule. Lobb and Davison (1977) presented pigeons a variety of multiple schedules with a second constant schedule available concurrently with both components of the multiple schedule. Unlike Nevin's results, their major finding was that relative response rates in the multiple schedule were independent of the rate of reinforcement associated with the constant schedule. The reason for the conflict between these results is uncertain, but the two studies did differ with respect to at least one major procedural feature. Lobb and Davison used a multiple schedule in which component transitions occurred only after a reinforcer was obtained, which had the effect of making the duration of the two components unequal and variable. Nevin, on the other hand, used the conventional procedure in which the component durations were equal and constant.

The generality of Nevin's results has been strongly supported by a recent study by McLean and White (in press). They presented a variety of multiple schedules on one response key, while a second schedule was associated with a second key that was concurrently available during both components of the multiple schedule. The sensitivity of the response ratios for the multiple schedule to the reinforcement ratios was assessed by Equation 1 and was found to be a function of the frequency of reinforcement associated with the concurrently available schedule, with higher reinforcement rates producing larger values of a.

Although the results of McLean and White, like those of Nevin (1974a), seem to favor Equation 2, they argued for a fundamentally different interpretation. Instead of the relative response rates being viewed as the product of interactions between the two components of the multiple schedule, they argued that behavior during each component depended solely on the alternative reinforcement present during the same component and was independent of the reinforcement in the alternative component. That is, multiple schedules can be regarded as two successively presented concurrent schedules, in which behavior during each component can be treated independently. Accordingly, performance during each component can be described by the matching law (cf. Baum, 1974), as represented by Equation 3. The terms of the equation are the same as for Equations 1 and 2, with the additions that B_{o_1} refers to behavior during Component 1 not measured directly, R_{o_1} to the reinforcement for that behavior, and b to the bias for the different types of reinforcement; hence,

$$\frac{B_1}{B_1 + B_{o_1}} = \frac{R_1^a}{R_1^a + b\,R_{o_1}^{\,a}}. \qquad (3)$$

Since the sum of B_1 and B_0 represent the total behavior that is occurring in Component 1 and is assumed to be a constant, k, Equation 3 can be rewritten as Equation 4, which gives the absolute response rates:

$$B_1 = \frac{k\,R_1^a}{R_1^a + b\,R_{o_1}^{\,a}}. \qquad (4)$$

And since a corresponding equation can be written for B_2, the relation between the response rates in the two components of the multiple schedule is given by their combination, as shown in Equation 5:

$$\frac{B_1}{B_2} = \left(\frac{R_1}{R_2}\right)^a \cdot \frac{R_1^a + b\,R_{o_2}^{\,a}}{R_2^a + b\,R_{o_1}^{\,a}}. \qquad (5)$$

Although McLean and White demonstrated that Equation 5 provides an excellent fit of all the studies in the literature in which alternative reinforcement was available concurrently with the multiple schedule and argued that it provides a general account of all multiple schedule "interactions," it is important to recognize one fundamental limitation of their analysis. Namely, it provides no explanation for the occurrence of contrast. Instead, it offers an account only of how response ratios may be differentially sensitive to reinforcement ratios, depending upon the amount of alternative reinforcement that is available. In order to extend their conception to contrast per se, it is necessary to make additional assumptions about interactions between R_{o_1} and R_{o_2}. The plausibility of such interactions will be discussed later in the treatment of Behavioral Competition Theory (e.g., Hinson & Staddon, 1978). For the present discussion, the important implication of the analysis given by McLean and White is that the sensitivity of response ratios to reinforcement ratios (as given by Equation 1) need say nothing about schedule interactions per se, but rather may be determined by factors totally independent of such interactions.

C. Component Duration, Matching, and Overmatching

1. *Contrast varies with component duration*

One of the most important empirical findings concerning contrast is that the degree of schedule interaction is greater the shorter the components of the multiple schedule (Ettinger & Staddon, 1982; Hinson, Malone, McNally, & Rowe, 1978; Schwartz, 1978a; Shimp & Wheatley, 1971; Spealman, 1976; Todorov, 1972; Williams, 1979, 1980). As shown in Figure 2, derived from McSweeney (1982), this is true for both positive and negative contrast. In her study, pigeons were changed from multiple VI 2-min VI 2-min to multiple VI 2-min EXT, or from multiple VI 2-min VI 2-min to multiple VI 2-min VI 15-sec. The data in Figure 2 are from only the constant VI 2-min component of both conditions. It is evident that the deviation from the baseline response rates was greatest with the shortest component duration, and generally the effects of component duration are symmetric for positive and negative contrast.

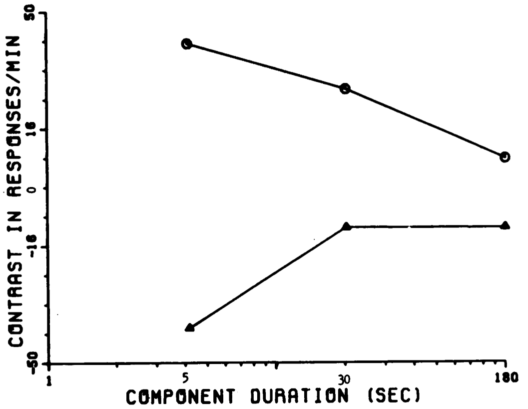

Fig. 2. Data taken from McSweeney (1982) showing the effects of component duration on the magnitude of positive (unfilled circles) and negative (filled triangles) contrast. The ordinate refers to the change in the absolute rate of responding for a constant VI 2-min component as a function of changing the alternative component from VI 2-min to VI 15-sec or to extinction. McSweeney also presented component durations other than those shown, but they were much longer than ordinarily used in multiple schedules and are excluded. The results shown are the average of five subjects. Note that the abscissa is a log scale.

One feature of component-duration effects not often recognized is that there appear to be two quite separate effects that work in opposite directions. To see this, consider a multiple VI EXT schedule. If the duration of the EXT component is varied while the VI component is held constant, response rate during the VI will be higher the longer the EXT component (Ettinger & Staddon, 1982; Wilton & Clements, 1971). But if the duration of the EXT component is held constant while the VI component is varied, the rate during the VI will be higher the shorter the component (Hinson et al., 1978). And the rate during the VI will be higher the shorter the component, when both components are varied simultaneously (Shimp & Wheatley, 1971; Williams, 1980). The implication is that variation in the duration of the VI component is stronger in effect than variation of the EXT component. Moreover, if, as seems likely, the response rate during the VI component is a different function of the two types of variation in component duration, the implication is that variations with both components of equal duration should be difficult to predict, since the two functions may have different shapes as well as different levels. As will be seen, such an implication is paradoxical, because schedule interactions with very short components are often highly regular.

2. *Matching as the limit of schedule interactions*

By far the most important aspect of the effects of component duration is that relative rates of responding in the two components "match" the relative rates of reinforcement when the duration of the components is very short (e.g., 10 sec). Such a finding suggests that contrast varies as a function of component duration only up to the level that matching is obtained. Moreover, with very short components, interactions in multiple schedules seem to obey the same principles as interactions in concurrent schedules, so it seems plausible that the same mechanisms are involved. Such implications thus pose powerful constraints on theories of contrast, because, as will be seen, several major theories must be questioned because they provide no conceptual rationale for why matching should occur.

Although matching in multiple schedules is widely accepted, the generality of the finding is in fact still open to question. With one exception that will be discussed later, there have been only three published studies that have used short-component multiple schedules in which the relative rate of reinforcement in the two components has been varied; these are Merigan, Miller, and Gollub (1975), Nevin (1974a), and Shimp and Wheatley (1971). Of these, only Shimp and Wheatley is a typical study of multiple schedules using rate of reinforcement, as Merigan et al. varied duration of reinforcement, and Nevin presented an FI schedule on a second key operating concurrently with both components of the multiple VI VI.

In order to assess whether matching occurred in these studies, the method suggested by Baum (1974, 1979) was used in which Equation 6 (below) is transformed into its logarithmic form (Equation 7) and a linear regression equation is fit by the method of least squares to find the parameters *a* and *b*. According to Baum (1974), the advantage of Equation 6 is that it allows the separation of bias effects from the true effects of relative rate of reinforcement. Accordingly, bias is reflected in deviations of *b* from 1.0, whereas the effect of relative rate of reinforcement is captured by *a*, which is 1.0 when matching is obtained. It is important to note that previous reviews of matching with concurrent schedules typically have found that slight "undermatching" is the most frequent finding, as the modal value of *a* is .80, rather than 1.0 (cf. Baum, 1979; Myers & Myers, 1977):

$$\frac{B_1}{B_2} = b\left(\frac{R_1}{R_2}\right)^a \quad \text{and} \qquad (6)$$

$$\log\frac{B_1}{B_2} = \log b + a\log\frac{R_1}{R_2}. \qquad (7)$$

Table 1 shows the results of the regression analysis for the individual subjects in the three studies of multiple schedules. In addition to the *a* and *b* estimates, the percentage of variance accounted for by the least-squares equation is shown in the third column for each subject. In parentheses next to the authors' citation is the number of data points fitted by the regression equation. The subjects of Shimp and Wheatley and of Merigan et al. are fit well by Equation 7, with more than 90% of the variance accounted for in every case. Bias was generally absent in both studies, since *b* was near 1.0. And except for Subject 1 of Merigan et al., *a* values were between .80 and 1.0, which is comparable to the findings for concurrent schedules.

The results for the subjects of Nevin (1974a) were not fit well by Equation 7. Not only was less variance accounted for, but the *b* values indicated considerable bias for all three subjects. This probably was due to the fact that the higher-density schedule was always associated with the same component throughout all of the conditions of Nevin's study. This also had the effect of reducing the range of reinforcement ratios that were studied (they varied from 1.5 to 4.5), so that the percentage of variance accounted for should be decreased by the restricted range. It is also possible that the poor fit of Nevin's data was due to the FI schedule running concurrently with the multiple schedule, which meant that the response rates controlled by the multiple were nonhomogeneous, varying widely with the periodicity of the FI.

Table 1

Results of the least-squares linear-regression solution of Equation 7 for existing studies of matching in multiple schedules. Component duration was 2, 5, or 10 sec for Shimp and Wheatley, 5 sec for Merigan et al., and 10 sec for Nevin. Note that the data from Merigan et al. come only from their two-key procedure. Matching was not obtained by them in a one-key procedure using the same relative reinforcement values. The numbers in parentheses next to the authors refer to the number of separate data points fit for each study.

	Subject	*a*	*b*	*Percentage of Variance*
Shimp & Wheatley (9)	13	.80	0.87	94.5
	15	.94	1.07	97.8
	20	.91	1.16	95.1
Merigan et al. (6)	1	.35	0.92	93.2
	2	.88	0.95	94.5
	3	.81	1.09	97.9
	4	.84	0.96	96.2
Nevin (6)	58	.39	1.95	79.0
	59	.61	1.41	56.8
	60	.58	1.30	77.3

The data in Table 1 provide considerable evidence that matching does occur in multiple schedules, just as it does with concurrent schedules. But the generality of this conclusion is challenged by the more recent study of Charman and Davison (1982), who failed to find similar results. Perhaps most relevant to the present discussion was their Experiment 2, which held component duration constant at 5 sec while varying relative rate of reinforcement in the two components. Unlike the results of Shimp and Wheatley (1971), matching did not occur, as a fit of Equation 7 to individual subjects yielded a median *a* value of .46, with a range for six subjects of .27 to .61. Moreover, these sensitivities were not notably different from those obtained in other experiments that involved longer component durations. Thus, their results demonstrate that matching need not occur when short components are involved.

But the implications of the results of Charman and Davison are unclear for several reason. First, their failure to find a major effect of component duration, independent of whether matching occurred, stands in strong conflict with many different studies of that variable (e.g., Figure 2). Second, the fit of Equation 7 to their individual subjects was considerably worse than that shown in Table 1. For example, several of the conditions in their Experiment 2 involved equal reinforcement schedules in the two components of the multiple. Despite equal reinforcement rates, the average difference in response rates was 10 responses/min for their conditions when the two components were presented on the same response key and 15 responses/min when the different components were presented on two different keys. Such differences were not due to systematic bias toward one particular component, as the component with the higher response rate varied over conditions. Moreover, in a substantial number of instances, response rates did not reverse when reinforcement rates were reversed, the result being that the component with the lower reinforcement rate produced the higher response rate (despite the use of a stability criterion). Such observations suggest that the weak control by the reinforcement ratios would have been improved if the strong hysteresis effects had not been present. This possibility is supported by the results of their last experiment in which reinforcement rates were held constant (which meant that hysteresis should be less a problem because no reversal in reinforcement ratios occurred) while component duration was varied. Unlike the results of their initial experiments, the last experiment demonstrated an effect of component duration.

The problem of hysteresis in multiple schedules has also been noted in my laboratory. In a variety of experiments using short component durations, subjects have shown strong sensitivity to the reinforcement ratios upon the first exposure to the schedule, but then apparently decreased in their sensitivity when the schedules were reversed. That is, the subjects frequently stabilized in their behavior after the reversal with a relative response rate substantially below the relative reinforcement rate (undermatching), despite having shown matching initially. The result is that an analysis in terms of Equation 7 usually yields a bias in favor of the component initially associated with the higher reinforcement rate. The problem in analyzing this effect has been that it does not occur under all circumstances and for all subjects. In particular, it is less likely when relatively lean, highly disparate schedules are involved and when the two components of the multiple are presented on different response keys (an effect shown by Merigan et al. but not shown by Charman & Davison). Whatever the determinants of the hysteresis effect, the important observation is that it need not occur. And, as shown by Table 1, studies in which it apparently was absent provide data that are fit remarkably well by Equation 7. The implication is that matching in multiple schedules is still a phenomenon that should be taken seriously.

A more fundamental problem for the generality of matching is that schedule interactions have been shown to be temporally asymmetric in character. That is, several experiments have shown that variation in reinforcement rate during the following component of a multiple schedule produces much stronger effects than variation of reinforcement in the preceding schedule (Williams, 1976a, 1979, 1981). For example, Williams (1981, Experiment 2) presented pigeons a three-component schedule in which reinforcement rate during the middle component was varied while the schedules during the first and third components were constant and equal. The critical finding was that variation of reinforcement during the middle component produced much stronger contrast effects during the first component than during the third component.

Given that schedule interactions are temporally asymmetric, the implication is that matching cannot occur in multiple schedules with more than two components. For example, in the three-component schedule used by Williams (1981), matching predicts that the relative response rate for a given component should be determined by its reinforcement rate relative to the total reinforcement rate across all components. But such a prediction is contradicted by the strong effects of temporal order that occurred. As will be discussed in later sections of the paper, the temporally asymmetric nature of contrast effects poses a major problem for all theories of contrast that have been proposed.

3. *Determinants of "overmatching"*

Although Table 1 does support matching as the limit of contrast interactions, Nevin (1974a) has argued that matching may be only one point on a more general function and that there is no reason, in principle, why the relative rate of responding should not exceed the relative rate of reinforcement (i.e., there is no reason why *a* should not exceed 1.0). The empirical basis for Nevin's claim comes from his study in which a multiple VI VI was presented concurrently with a FI 50-sec schedule on a second key. Although he reported that the average response rates in the multiple approximated matching (however, Table 1 shows this is an oversimplification), the local response rates, recorded for the different portions of the FI, departed from matching in both directions. As shown in Figure 3, undermatching occurred in the multiple schedule during the early portions of the FI, but overmatching occurred later in the FI. The apparent implication is that overmatching may occur in other circumstances as well.

However, there are two problems with accepting Nevin's finding of overmatching at face value. The first is the substantial bias effect in his study, as shown in Table 1. This means that the relative response rates reported by Nevin cannot be taken as a true index of the sensitivity to relative reinforcement rate, since all of the functions in Figure 3 would be displaced downwards if the bias effect were removed. The second problem is that Nevin reported relative reinforcement rates for the multiple schedule summed over all portions of the FI, rather than separate reinforcement rate for each FI segment. Since the response rates during the multiple schedule were greatly reduced near the end of the FI, this meant that the obtained reinforcement rates were likely to differ substantially from the programmed rates. Moreover, it is likely that the deviation from the programmed rates was greater for the lower-valued VI component, since its response rates during the last segment of the FI were often in the critical range of 0 to 5 responses/min. Thus, if the obtained reinforcement rates had been reported, it is possible that the pattern of "overmatching" shown in Figure 3 would have been predicted by the reinforcement ratios themselves.

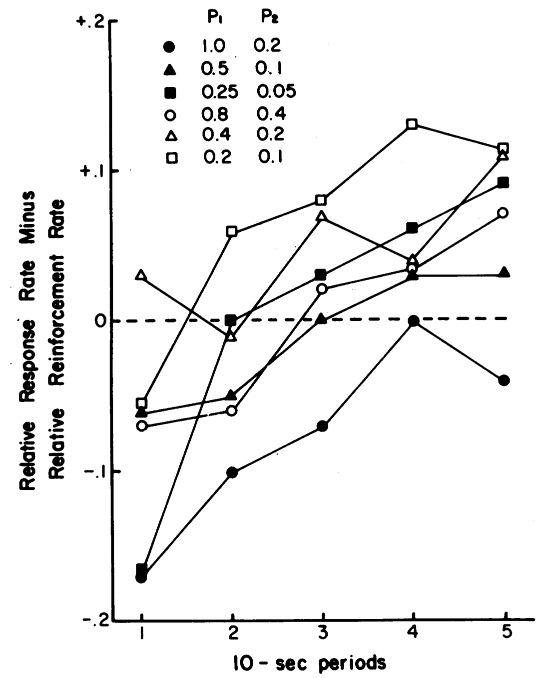

Fig. 3. Data taken from Nevin (1974a, his Figure 6) showing how relative response rates in a multiple schedule deviated from relative reinforcement rates. The expected value of the relative reinforcement was either .80 (filled symbols) or .67 (unfilled symbols), so that the maximum amount of deviation that was possible differed accordingly. The abscissa represents the portion of the FI schedule that was present on the second key. The data are averages of three subjects for each of the pairs of reinforcement schedules that were used in the multiple, represented by different function. A *P* value of 1.0 corresponded to a VI 30-sec schedule, a *P* value of .5 corresponded to VI 60-sec, etc.

Although the preceding discussion shows that the evidence for overmatching is not convincing, the potential importance of matching for theories of contrast implies that the issue should receive much closer attention. Accordingly, Williams (Note 2) investigated the phenomenon with a procedure similar to Nevin's (1974a) but with several modifications designed to facilitate the interpretation. Associated with one response key was a multiple VI 2-min VI 6-min schedule, with alternating 10-sec components. After baseline training with the multiple in isolation, a signaled VI schedule was added to the second key. Thus, the second key was illuminated only when the signaled VI reinforcers were available, so any effects of this additional reinforcement should be due to changes in the context of reinforcement, per se, rather than to response competition.

Figure 4 shows the results, averaged over four subjects. During the initial baseline, the relative rate of responding approximated the relative rate of reinforcement, as both were near .75. The addition of the signaled VI (initially a VI 30-sec) greatly reduced the absolute response rates in both components of the multiple, with much larger effects in the VI-6 component. Consequently, the relative rate of responding increased. However, part of this increase was due to a change in the obtained distribution of reinforcement, since several of the subjects had such low response rates in the VI-6 component that several of the scheduled reinforcers were not obtained. To reduce this confounding, the signaled VI was changed to VI 60-sec, and the obtained distribution of reinforcement then did return to near its scheduled value. The elevation in the relative response rates still remained, however, showing that overmatching was a genuine phenomenon.

Although the results shown in Figure 4 provide considerable support for Nevin's discussion of matching and overmatching, their interpretation is still problematic. The reason is that the overmatching phenomenon has not consistently held up over systematic variation of the schedule parameters. Although we have successfully replicated the effect seen in Figure 4 in two separate experiments when the signaled VI schedule was added for the first time, continued training in which the schedules in the multiple components were varied often resulted in the reintroduction of the signaled schedule having no differential effect. That is, the reintroduction of the signaled VI always produced substantial suppression of multiple schedule response rates, but the degree of suppression was not proportionally greater for the lower-density component, as overmatching requires. This suggests that overmatching is not a general property of multiple schedule interactions, at least for those that are steady-state. Why it occurs when the signaled VI is added initially is uncertain, and until that uncertainty is reduced, the status of matching as the limiting form of multiple schedule interactions will remain in doubt.

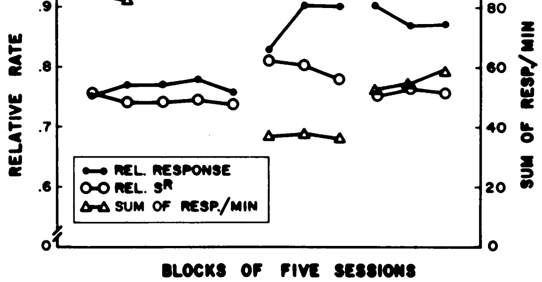

Fig. 4. The effects of adding a signaled VI schedule to a multiple VI 2-min VI 6-min, taken from Williams (Note 2). Shown separately are relative response rate, relative reinforcement rate, and absolute response rates summed over both components of the multiple. Data are averages of four subjects.

D. Effects of Species, Stimulus Location, and Type of Response

1. *The case against the generality of contrast*

The discussion of the previous sections has been predicated on the assumption that contrast is a general phenomenon, with some underlying set of behavioral principles that remains to be discovered. The research now to be described suggests that this assumption is ill-founded, because contrast does not occur in all circumstances. Moreover, the nature of the situations where contrast apparently does not occur has been taken as strong evidence for a particular theoretical interpretation (cf. Rachlin, 1973; Schwartz & Gamzu, 1977).

Evidence against the generality of contrast has come from three separate generalizations: (1) Contrast does not usually occur with rats as subjects; (2) contrast does not occur with pigeons as subjects when the discriminative stimulus is not located on the response key, and (3) contrast does not occur with pigeons when the response is something other than the key peck. Taken together, these three generalizations have been regarded as strong evidence for additivity theory, which holds that contrast is due to elicited pecks being evoked by the Pavlovian contingency between the stimulus and reinforcer. As will be seen, however, the validity of all of these generalizations is suspect, as either there are clear empirical exceptions to them or the evidence that supports them can be shown to be of questionable significance.

2. *Effects of species*

Of the three generalizations that have been cited, the one with the least empirical justification is the claim that contrast is restricted to the use of pigeons as subjects. There are now a large number of studies showing robust contrast effects with rats (Beninger & Kendall, 1975; Blough, 1980; Bradshaw, Szabadi, & Bevan, 1978; Gutman, 1977; Gutman, Sutterer, & Brush, 1975; Nallan & McCoy, 1979; Uhl & Homer, 1974), and with other species, including humans (Rovee-Collier & Capatides, 1979; Waite & Osborne, 1972). One wonders why the generalization was ever taken seriously, since there were clear demonstrations with rats even prior to the development of additivity theory (e.g., Padilla, 1971; Wilkie, 1972). It may be that contrast is a more robust phenomenon with pigeons, but even this weaker claim seems to have little empirical justification in light of recent empirical investigations (e.g., Bradshaw et al., 1978; Nallan & McCoy, 1979).

Although contrast clearly does occur with subjects other than pigeons, a major empirical issue remains unresolved. Namely, do the contrast effects that occur with other species obey the same functional relations? This issue is important because there is increasing reason to believe that contrast may occur for several different reasons, so it may be that the nominally similar effects with different species are in fact functionally quite different. For example, there is no clear evidence that contrast varies with component duration in any species other than pigeons. Similarly, matching in multiple schedules also has not been demonstrated with other species. Given the central importance of such phenomena for the theoretical interpretation of contrast, their investigations with experimental preparations not involving pigeons would go far in clarifying whether common, general laws of behavior are involved.

3. *Effects of stimulus location*

Although several studies (Redford & Perkins, 1974; Schwartz, 1974, 1975) have failed to find contrast when the discriminative stimuli were located off the response key (e.g., when a houselight or tone was used), this generalization, like that regarding the effect of species, has not withstood further empirical research. The studies showing contrast with rats provide one major source of evidence against the generalization, since all of them used discriminative stimuli located off the response lever (bar pressing was typically the response, and either a houselight or a tone was the discriminative stimulus). Given the magnitude of the contrast effects obtained in those studies, the implication is that stimulus location is not a crucial variable. Moreover, several investigations with pigeons also have shown contrast with off-key discrimination procedures (Bouzas & Baum, 1976; Farthing, 1975; Hemmes, 1973; Westbrook 1973).

Given the theoretical stakes involved, some consideration is needed for why the different studies have yielded such inconsistent results. One possible explanation is that there are two sources of contrast, one dependent on stimulus location because of the involvement of the stimulus-reinforcer contingency and one independent of stimulus location because relative rate of reinforcement has general effects on behavior that are not mediated by the Pavlovian contingencies. Such a possibility is supported by several studies showing that contrast effects typically are substantially larger with keylight stimuli than with off-key discriminative stimuli (e.g., Hearst & Gormley, 1976).

Although the notion that contrast occurs for several separate reasons is now accepted by a number of investigators (e.g., Schwartz, 1978a), a closer consideration of the results of the studies that have employed off-key discriminations challenges whether such a concession is actually forced by the data. As argued by Williams and Heyneman (1981), the effects of stimulus location on the magnitude of contrast need not be taken as evidence for the importance of stimulus-reinforcer contingencies, because off-key discrimination procedures provide a flawed assessment of the degree of contrast. Because the issues raised by Williams and Heyneman are critical for interpreting a large segment of the recent literature on contrast, their arguments will be recapitulated here.

The problem with off-key discrimination procedures is that they confound changes due to reinforcement variables with changes in the behavioral unit. To appreciate what is meant by the behavioral unit, consider the off-key discrimination procedure that has been used most frequently, the "signal-key" procedure first developed by Keller (1974). The critical feature of the procedure is that the response requirement for both components of the schedule is always associated with the same stimulus, whereas the discriminative stimuli are located on a second response key, which has no response requirement. The typical finding has been that contrast does not occur when the "operant" key is considered in isolation (but see Table 1 of Williams & Heyneman, 1981, for a listing of numerous exceptions). What happens instead is that the contrast manipulation (e.g., multiple VI VI changed to multiple VI EXT) results in the development of pecking to the signal key, despite the fact that such behavior has no effect on the delivery of reinforcement.

The failure of "operant-key" contrast in the signal-key procedure is not critical evidence because the operant response unit is likely to be quite different depending upon whether nondifferential or differential reinforcement is in effect. During the baseline with nondifferential reinforcement, the pigeons may completely ignore the stimulus on the signal key because it contains no information, i.e., the schedule is the same regardless of the stimulus that is present. The most likely behavior is to orient only to the operant key. But with differential reinforcement in the contrast manipulation, the signal key should gain stimulus control, so that the animal's orientation should switch back and forth between the operant and signal keys. In other words, during the baseline the animal may look straight ahead and peck the key, but during the contrast manipulation it will alternate pecking with looking. Given that looking at the signal key should interfere with operant-key pecking, it should not be surprising that the increase in responding on the operant key that is expected from the contrast manipulation is less likely to occur.

Although the confounding effect of changes in the behavioral unit is most easily seen with the signal-key procedure, it is also likely to occur with other off-key procedures where control by an off-key stimulus is unlikely to occur during the baseline with nondifferential reinforcement. This means that the behavioral unit created by the three-term contingency may be altered by the change from nondifferential to differential reinforcement, and there is often no way of knowing whether the new behavioral unit is commensurate with the previous unit. Given that uncertainty, it should not be surprising that the results of off-key discrimination procedures have been quite variable.

In support of their argument about the importance of the behavioral unit, Williams and Heyneman (1981) reported the results of a signal-key experiment in which stimulus control by the signal was insured during the baseline phase with nondifferential reinforcement. Instead of a single operant key, two separate operant keys were used, such that during one discriminative stimulus (on the center key), responses to the left key were reinforced, while during the second discriminative stimulus responses to the right key were reinforced. Reinforcement during the second discriminative stimulus was then discontinued, with the result that "operant-key" contrast occurred during the first discriminative stimulus for all subjects. The occurrence of contrast with the three-key procedure was predicted because stimulus control by the signal key was required during both the baseline and contrast manipulation, so that the response unit should not be strongly affected by shifts between nondifferential and differential reinforcement. To the extent that such results can be generalized to other off-key procedures, the implication is that stimulus location is a critical determinant of contrast only to the extent that its effects on response topography are uncontrolled.

4. *Effects of response type*

The final generalization to be evaluated in this section is that contrast occurs only when the operant response is the same as the consummatory response associated with the reinforcer. Such a generalization was encouraged by early studies showing that contrast failed to occur with pigeons that were trained to treadle press (Hemmes, 1973; Westbrook, 1973). As with the two generalizations already considered, however, this claim also fails to hold up. It is true that more recent studies have agreed with the earlier work in showing that treadle pressing is less sensitive to contrast than is key pecking when the two are explicitly compared (Davison & Ferguson, 1978), although substantial contrast has been obtained under some circumstances (McSweeney, 1983). But it is not at all clear that the different sensitivities have anything to do with the similarity between the operant and consummatory responses. For example, Jenkins (1977) has argued that different response systems may differ systematically in their sensitivity to all contingencies, whether response-reinforcer or stimulus-reinforcer, so that treadle pressing may simply be an insensitive response. This becomes a plausible interpretation when the treadle-pressing results are considered in light of the results with bar pressing of rats. That is, robust contrast effects do occur with bar pressing, and there is no reason to believe that it is any different from treadle pressing in pigeons, either in terms of similarity to the consummatory response or in terms of the role played by the location of the discriminative stimulus.

Why responses vary in their sensitivity to schedule interactions is uncertain, but one plausible explanation is that they also differ in their sensitivity to negative induction (the generalization of inhibitory effects when the response is extinguished in the alternative component). Contrast and negative induction often are regarded as antithetical, but in fact both may be operative in the same situation. Their simultaneous detection is, of course, impossible when a single response measure is used, since by definition only one of the other effects can occur. But when a second response measure is taken (e.g., IRT distribution, the pattern of local response rate), there is often evidence that negative induction is an important feature of contrast procedures, even when overall contrast has been demonstrated (Freeman, 1971a; Gutman & Sutterer, 1977; Marcucella & MacDonall, 1977). Thus, the magnitude of overall contrast may be reduced because the competing effects of negative induction must be surmounted.

If negative induction is recognized as an effect separate from contrast, a rationale can be given for why different responses may vary in their sensitivity to induction. Intuitively, it would seem that responses with complex topographies, which require considerable shaping, would be most susceptible, perhaps because of the relative degree of stimulus control exerted by exteroceptive vs. interoceptive events. The concept of a complex operant implies that some features of the response are under control of other parts of the response. Thus, the total fraction of the stimulus complex that is interoceptive is considerably greater with a complex operant, which means that a larger portion of the stimulus complex is shared by the two components of the multiple schedule. Thus, the switch to extinction during one component of the schedule changes not only the associative value of the discriminative stimulus that is uniquely associated with that component, but also the value of the interoceptive aspects of the stimulus complex, which continue to play a role in response execution. The result is that the response-suppressive properties of extinction should be likely to produce negative induction due to the shared interoceptive stimuli. Such an interpretation is, of course, only speculation, but some speculation seems justified by the repeated demonstration of inconsistent results in procedures that appear conceptually to be quite similar.

E. THE RELATIONSHIP BETWEEN TRANSITORY, TRANSIENT (LOCAL), AND STEADY-STATE CONTRAST

1. *Contrast has a transitory component*

Terrace (1966) presented substantial evidence that contrast is a byproduct of discrimination learning in which the negative stimulus (S−) acquires aversive properties because of its association with nonreinforced responding. Such a view, if correct, would undermine most of the preceding discussion, since Terrace's account would obviate any attempt to define general controlling principles by which relative rate of reinforcement exerts its effects. As is now well known, however, Terrace's account is incorrect, at least as a general theory of contrast, as a variety of subsequent research has consistently failed to show any consistent relation between the amount of S− responding and the occurrence of contrast (cf. Kodera & Rilling, 1976).

A major piece of evidence in favor of Terrace's view was that contrast disappeared after prolonged discrimination training (Terrace, 1966). Subsequent work has again failed to confirm this finding, however, as contrast has been found to persist even after 60 to 70 sessions of training (Hearst, 1971; Selekman, 1973). However, it is important to recognize that there is evidence that the magnitude of contrast does sometimes (but not always) decrease over sessions. Several different studies (Bloomfield, 1966; Sadowsky, 1973; Selekman,

1973) present data showing that the maximum rate of responding occurs in the first few sessions of discrimination training and then declines to an asymptote that is above the baseline value. On the basis of this pattern, Bloomfield (1966) speculated that contrast has two components, "peak" contrast, which is related to the amount of S− responding, and a general contrast effect that is controlled only by the relative rate of reinforcement. But several studies have found no effect of any kind of the amount of S− responding (cf. Kodera & Rilling, 1976), so the generality of "peak" contrast is uncertain. In our own laboratory the effect has occurred only sporadically and seems to be related to the difficulty of the discrimination, although we have not studied this relationship systematically.

2. *The relationship between transistory and transient (local) contrast*

Terrace (1966) also presented evidence that the occurrence of contrast was correlated with a differential effect of the preceding stimulus. That is, response rates during the S+ were higher following a prior S− presentation than following a prior S+ presentation. When this difference as a function of the preceding stimulus disappeared, so then did the occurrence of contrast. The interpretation given by Terrace was that contrast was due to the aversive properties of the just-preceding stimulus producing a "rebound" energizing effect.

Subsequent research has confirmed Terrace's finding that the effect of a preceding S− tends to disappear with continued training. Much of this work has examined local response rates within the S+ component and has shown that early in training the local rate is elevated at the start of the S+ presentation, but later in training the pattern of local rate becomes relatively flat. The result is that the overall contrast effect decreases in magnitude with continued training because the contribution of the local-rate elevation, which can be substantial under some conditions, is lost (cf. Malone, 1976). It is important to emphasize that a substantial amount of overall contrast still remains after the disappearance of local contrast. Thus, a reasonable interpretation is that contrast, at least that which occurs early in discrimination training, has two separable components.

3. *Determinants of local contrast*

Terrace (1966) has not been alone in claiming that contrast is dependent on a "rebound" effect of a preceding S− presentation. Rachlin (1973) has proposed a similar notion in his discussion of additivity theory, although the mechanism by which the prior S− presentation exerts its effects is quite different. According to Rachlin, contrast occurs because the S+ elicits autoshaped pecking owing to its Pavlovian stimulus-reinforcer contingency, and the signal value of the S+ is maximal at its onset. Additivity theory will be discussed extensively in a later section, so we will note for the moment only that Rachlin's position implies that local and overall contrast are inextricably intertwined, as overall contrast should never occur in the absence of local contrast.

The strong relationship between local contrast and overall contrast that has been found in several studies (e.g., Green & Rachlin, 1975; McLean & White, 1981; Spealman, 1976) would seem to provide strong evidence for Rachlin's account. However, the issue is not whether local contrast may be an important component of overall contrast, since many studies agree that local contrast plays a major role under some circumstances. The issue instead is whether there is a necessary relationship between local and overall contrast, and a variety of studies show that no such relationship exists (e.g., Boneau & Axelrod, 1962; Catania & Gill, 1964; Mackintosh, Little, & Lord, 1972; Malone, 1976; Nevin & Shettleworth, 1966). In all of these, local contrast was a contributor to the level of overall contrast early in training but then disappeared with continued training. The result was that a substantial amount of overall contrast remained in the absence of any evidence of local contrast.

Some proponents of additivity theory (Schwartz, 1978a; Schwartz, Hamilton, & Silberberg, 1975) have argued that local contrast need not be correlated with the occurrence of overall contrast, but that it nevertheless is a good index of the contribution of elicited behavior to that overall contrast. The evidence for this position comes from the signal-key procedure, in which the elicited behavior to the signal key exhibits very pronounced local-rate elevations while the local rate to the operant key is relatively flat (Schwartz, 1978a; Spealman, 1976). But even this weaker claim about the status of local contrast is questionable, since the major determinants of local contrast outside of the signal-key procedure seem to be orthogonal to the mechanisms invoked by additivity theory. Not only does local contrast disappear with continued training (Malone, 1976; Williams, 1981, 1982; Nevin & Shettleworth, 1966), it also depends crucially on the number and similarity of the discriminative stimuli (Malone, 1976) and whether the preceding extinction component is fixed or variable in duration (Hinson & Staddon, 1981). Additivity theory, as presently stated, offers no account for such effects.

Perhaps the most instructive evidence regarding the determinants of local contrast comes from a comparison of the effects of timeout (TO) with those of an explicit S− presented on the response key. A variety of data have shown that contrast occurs when an S+ is alternated with TO, despite the absence of nonreinforced responding (cf. Mackintosh, 1974, p. 375). Vieth & Rilling (1972) compared the pattern of local response rate as a function of whether TO or a keylight S− was the source of contrast. Although there was relatively little difference between the two conditions in the overall level of contrast, there was a systematically greater local contrast effect at the start of the S+ under the S− condition. Malone (1976) provided a more systematic study of this difference, showing relatively flat local-rate gradients when the S+ was alternated with TO but substantial local-contrast effects when an S− was substituted for TO. The local-contrast effect then disappeared with continued discrimination training but could be reinstated when a new S−, more similar to the S+, was substituted. Malone's results leave little doubt that local contrast is primarily the result of the process of discrimination, and he interprets his findings as an instance of Pavlovian induction (i.e., a rebound effect of release from inhibition).

The functional independence of local and overall contrast is further demonstrated by the results of Williams (1981, Experiment 2). He presented pigeons with a three-component schedule that involved the recycling sequence of ABC, ABC, etc. The schedules during Components A and C were held constant at VI 3-min, while the schedule during Component B was initially VI 1-min and then changed to VI 6-min. Figure 5 shows the local response rates during Components A and C that were produced at various points in training. To the extent that local contrast is a major determinant of overall contrast, the prediction is that response rates should be suppressed during Component C when the VI 1-min schedule occurred in Component B, whereas the rate in Component C should be enhanced when the schedule was changed to VI 6-min. The first segment of Figure 5 shows that this prediction was correct during the first 10 sessions of training, as the differences between Components A and C were determined by the local negative contrast that occurred at the beginning of Component C (unfilled circles). However, as training continued, an overall contrast

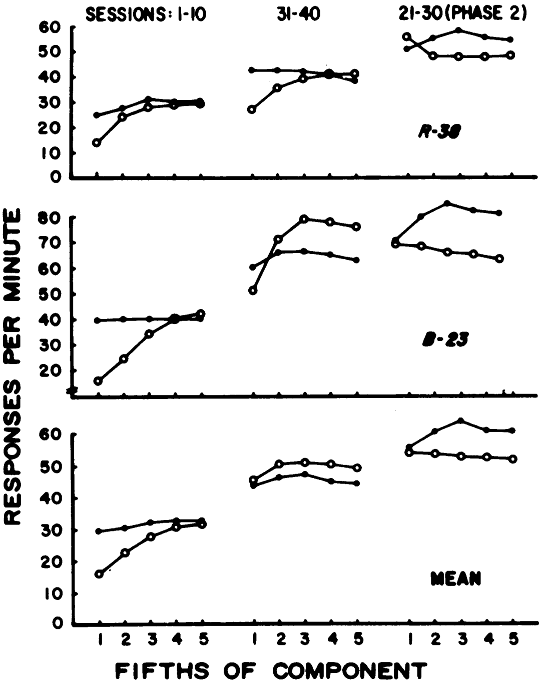

Fig. 5. Local rates of responding obtained in the first and third components of a three-component schedule, taken from Williams (1981, his Figure 7), during which the schedules were constant and equal during the first and third components but varied during the second component. The filled circles correspond to the first component, the unfilled circles to the third component. The first and second segments present local rate from the designated sessions of Phase 1, in which the schedule during the second component was VI 1-min. The third segment presents data from Phase 2, in which the schedule during the second component was VI 6-min. The top two panels show data for selected individual subjects. The bottom panel shows the mean results for all four subjects in the experiment.

effect appeared that was in the opposite direction of local contrast. Thus, the higher average response rate occurred during Component C, despite the local contrast persisting at the beginning of the component for some subjects (e.g., Pigeon B-23). The opposite pattern then occurred when the schedule in Component B was changed to VI 6-min, as the higher average rate occurred in Component A. The implication is that local contrast and overall contrast have no necessary relationship and can be procedurally dissociated.

F. Temporal Asymmetry in Steady-State Contrast

1. *The following schedule as the dominant variable*

All of the preceding discussion is consistent with the view that the primary variable controlling multiple schedule interactions is relative rate of reinforcement. The findings discussed in the preceding section on local contrast suggest that other variables are involved under some circumstances (e.g., discrimination difficulty), but these need not operate in steady-state situations.

The issue discussed in the present section is how relative rate of reinforcement should be characterized. One possibility is that it is a primitive variable, not reducible to any more basic mechanism, so that the effect of any occurrence of reinforcement is relative to the context of reinforcement in which it is presented (cf. Herrnstein, 1970). Such a view does seem to provide a meaningful description of data from several different situations (cf. de Villiers, 1977; de Villiers & Herrnstein, 1976). But the evidence reviewed in this section argues against this generalization. The reason is that the context of reinforcement, at least for multiple schedules, is temporally asymmetric in its effects. Moreover, the direction of the asymmetry is just the opposite of that usually proposed. That is, the alternative reinforcement that precedes some target component produces little if any schedule interaction, whereas the alternative reinforcement that occurs subsequent to the target behavior produces strong interactions. The implication is that the context of reinforcement cannot be defined simply in terms of the total (or average) reinforcement in the situation. Instead, contrast is best viewed as an anticipatory effect, in that response rate in the target component is inversely related to the rate of reinforcement that is impending in the succeeding component.

The importance of the following schedule of reinforcement has been known for many years. It was first demonstrated by Pliskoff (1961, 1963) and first studied systematically in the context of multiple schedules by Wilton and Gay (1969). Yet all of the early investigations of the following-schedule effect have been ignored completely by recent theoretical analyses of multiple schedule effects (cf. de Villiers, 1977; Mackintosh, 1974; Schwartz & Gamzu, 1977). Since I will argue that the following-schedule effect is the fundamental basis of contrast, some elaboration is perhaps needed for why it has been so neglected.

Previous theoretical analyses of contrast can be viewed as a contest between theories that view contrast as a rebound effect depending on the reinforcement conditions of the just-preceding component, and theories that view contrast to be the result of the molar variable of relative rate of reinforcement, so that the just-preceding component has no special status. Early work (e.g., Bloomfield, 1966; Nevin & Shettleworth, 1966) suggested that both variables could operate simultaneously, although the rebound effect of the preceding component was more likely to be transitory. Thus, molar relative rate of reinforcement was taken as the variable controlling steady-state contrast, until the development of additivity theory. Partly as a result of Rachlin's (1973) influential version of additivity theory, emphasis shifted once again to the transition between components, since Rachlin argued that the signal value of the discriminative stimuli was at its maximum at the point of component transition. Consequently, the local contrast effect that occurred at the beginning of the S+ received renewed interest as a crucial feature of steady-state contrast.

In virtually all of this research, the multiple schedules that were studied had only two components. Thus, separation of the different controlling variables (component transition vs. molar relative rate of reinforcement) was impossible if contrast was measured solely in terms of the average response rate. Previous research attempted to surmount this problem by generating two additional measures, the pattern of local response rate within the component and the differential effects of different orders of presentation (e.g., response rate after a preceding S+ vs. after a preceding S−). This restriction on the methodology of previous research is important to recognize, because it implies that any effect of the following schedule could be revealed only if one of these two additional measures were sensitive to it. Order of presentation could not in principle provide such information, since the impending component was always varied randomly. This left only the pattern of local response rate as an indicator of the following-schedule effect, and we now know that local rate is sensitive to the following schedule only under some circumstances (cf. Williams, 1982). The result is that any effect of the following schedule was unlikely to be detected in previous research, since its effect was always confounded with that of molar relative rate of reinforcement.

My own interest in the phenomenon was kindled by a totally serendipitous finding (Williams, 1974). Pigeons were trained on a successive discrimination in which the S+ and S− were alternated irregularly, such that no more than two S+ presentations occurred in succession (which meant that the second S+ was always followed by extinction). Responses during presentations of the S+ following a preceding S+ were recorded separately from those during presentations following a preceding S−, with the unexpected result that most subjects developed higher rates of responding during the former. Subsequently, Buck, Rothstein, and Williams (1975) investigated the phenomenon using local response rates as a measure, with the major finding that local response rate increased gradually throughout the S+ component, being highest near the transition to the next extinction component.

Because subsequent investigations have frequently failed to find the increasing local-rate patterns reported by Buck et al., Malone (1976) suggested that the pattern was an artifact of negative induction occurring at the beginning of the component, rather than an increase in the contrast effect as the end of the component was approached. Evidence against this interpretation is seen in Figure 6 (taken from Williams, 1982), which shows the patterns of local rate generated by a multiple VI EXT after separate training with 30-sec and 150-sec components. Increasing local-rate gradients occurred for all subjects with the 30-sec components, but more variable gradients occurred with the 150-sec components. Of greatest interest are the results for Subject R-11, which exhibited a nonmonotonic gradient. Its local rate was elevated just after the transition from extinction, then decreased, and then gradually increased as the end of the component (the transition to extinction) was approached. The occurrence of both types of local-rate effects provides strong evidence that the increasing local-rate gradients reported by Buck et al. are independent of the occurrence/nonoccurrence of local contrast at the beginning of the component.

It should not be surprising that the pattern of local rate is not a reliable index of the following-schedule effect, since such gradients depend critically upon temporal discrimination of the different portions of the component, which has proved to be disrupted easily (e.g., the local-rate gradients are difficult to recover after a reversal of conditions). To avoid this problem, subsequent research (Williams, 1976a, 1976b, 1979, 1981) has used multiple schedules with more than two components, which allows

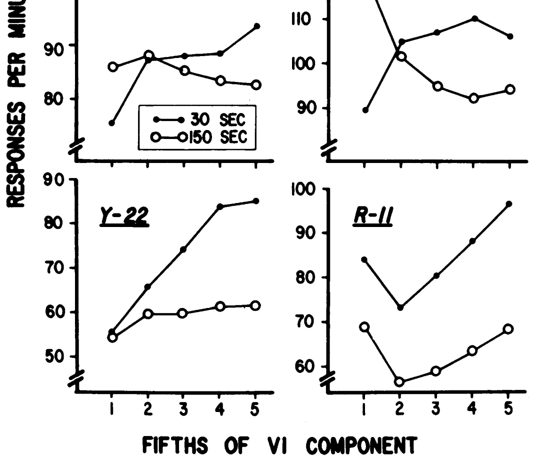

Fig. 6. Local response rates for individual subjects trained on a multiple VI EXT schedule. Separate functions for each subject represent the local response rates obtained from different segments of the VI component. Data are those from the last four sessions of exposure to each component duration, taken from Williams (1982, his Figure 3).

the effect of the following schedule to be revealed more directly. An example of such a procedure is provided by Williams (1981), who varied the rate of reinforcement in only one component of several three- and four-component schedules. The rationale of the study was that changes in response rate should occur only in the unchanged component that was followed by the variable component, to the extent that the following schedule was the dominant variable. On the other hand, it is possible that all of the unchanged components would show at least some effect of the variation, suggesting that there are several sources of contrast. Portions of the results of that study are shown in Figure 7, which depicts the mean results of four subjects trained on a three-component schedule in which the first and third components were always associated with identical VI 3-min schedules, and the middle component was associated with either VI 6-min or VI 1-min (shown by the designation above each segment of the graph). In addition, the last two segments of the figure show the effects of adding a timeout (TO) after each cycle of the three-component sequence. The stimulus-reversal designation below the second segment refers to the interchange of the stimuli associated with the first and third components while holding all of the reinforcement schedules constant.

The major observation from Figure 7 is that response rate during the third component (unfilled circles) changed very little as a function of changing the schedule during the middle component (in particular, compare the second and third segments, and the fourth and fifth segments) but changed dramatically when TO was introduced following the third component (compare the third and fourth segments). In contrast, responding during the first component (filled circles) changed substantially as a function of the schedule in the middle component but was largely unaffected by the introduction of the TO. Apparently, therefore, essentially all of the effects of changing the relative rate of reinforcement were due to the following-schedule effect.

The results shown in Figure 7 represent only a portion of the manipulations investigated by Williams (1981), and the remaining conditions corroborated the major finding that the dominant variable was the following schedule of reinforcement. However, some individual sub-

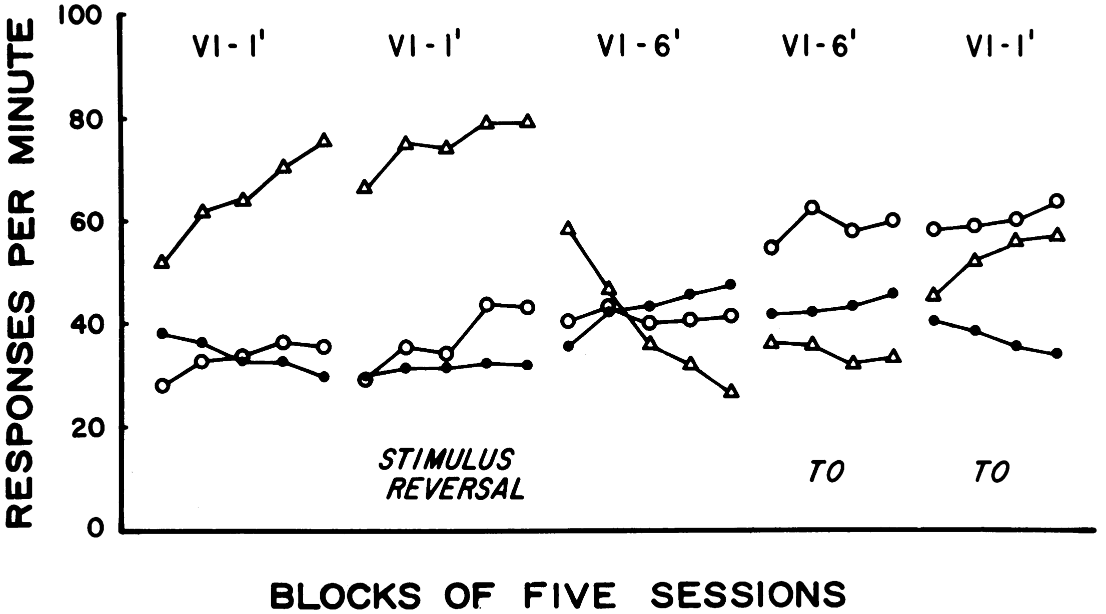

Fig. 7. Results of a three-component multiple schedule in which the reinforcement rate was varied during the middle component, taken from Williams (1981, his Figure 8). The filled circles depict the response rate in the first component, the triangles the rate in the middle component, and the unfilled circles the rate during the third component. The schedule for the middle component is shown above each segment. The schedule for the first and third components was always VI 3-min. The TO designation refers to a timeout being added after each complete cycle of the sequence (following the third component).

jects did show contrast effects that could not be accounted for by the following schedule. But such effects cannot be taken as support for a role of overall relative rate of reinforcement, independent of the following-schedule effect, because closer analysis revealed that they were due to the local effects of the preceding schedule. It should be emphasized that these residual effects were usually quite small, variable from condition to condition, and did not occur for all subjects. Such characteristics are like those previously reported for local contrast (cf. Malone, 1976).

Further evidence that local contrast is functionally different from contrast due to the following schedule comes from Farley (1980a, Experiment 5). He presented pigeons multicomponent schedules such that the effect of changing one of the components to EXT could be observed separately for the preceding and following components. Contrast occurred in both locations, with the following-schedule effect marginally larger. But most importantly, Farley also measured the power of the stimulus associated with contrast to serve as a conditioned reinforcer (by using it as the last stimulus of a chain schedule that was interspersed with training on the multiple). The major finding was that the stimulus associated with contrast due to the preceding component had no significant increase in its reinforcing powers due to the contrast procedure, but the stimulus associated with contrast due to the following schedule had a substantial increase. Farley interpreted this finding to suggest that the following-schedule effect reflected a genuine increase in "response strength," whereas the "rebound" form of contrast did not. This conclusion suggests that the two types of contrast are independent effects, and the following-schedule effect is the fundamental basis of steady-state contrast.

2. *The issue of generality*

The research just described provides important evidence that the following-schedule effect is the primary cause of interactions in steady-state multiple schedules. But its dominant role appears to be challenged by several negative findings. One such challenge comes from studies examining the effects of signaled TO. Using pigeons as subjects, Leitenberg (1966) reported that a stimulus superimposed on a VI baseline produced a rate increase if the stimulus terminated in TO. Such an effect is obviously related to the following-schedule effect, since it is similar to alternating the VI component of a multiple schedule with an EXT component (also see Figure 7). Unfortunately, subsequent efforts to demonstrate the effect with rats as subjects failed to produce a rate increase during the pre-TO signal and in fact produced a rate decrease (Kaufman, 1969; Leitenberg, Bertsch, & Coughlin, 1968). As yet there is no clear explanation for what these failures mean for the generality of the following-schedule effect in multiple schedules. The discrepant findings do underscore, however, the need to investigate the functional relations that govern the occurrence of contrast with rats, since it is the existence of common functional relations, not just the occurrence of contrast per se, that is crucial in establishing the generality of the behavioral laws that are involved.

Despite the negative results of Leitenberg et al. (1968) and Kaufman (1969), there is other evidence that suggests that the following-schedule effect does occur with rats. Bacotti (1976) trained rats on a VI food schedule in which the rats were fed immediately after the session was terminated (in their home cages) or had their feeding delayed one hour. When food was given immediately, response rates during the session declined during the last 15 minutes. However, there was no decrease in response rate when the feeding was delayed.

Still other positive evidence with rats as subjects comes from Flaherty and Checke (1982), who presented rats with a saccharin solution to drink followed by the opportunity to drink a sucrose solution. The result was that the amount of saccharin consumed was reduced by the following presentation of sucrose (which was preferred over saccharin), and the amount of the decrease was greater the closer in time the sucrose presentation occurred. These results are particularly intriguing because they extend the following-schedule effect to a consummatory response rather than a free-operant response, which suggests that changes in the hedonic value of the reinforcer may be an important determinant of the effect.

But evidence against the generality of the following-schedule effect also comes from studies with pigeons as subjects. Rowe and Malone (1981) trained pigeons on a seven-component multiple schedule in which all of the components were associated with a VI during the baseline, and then five of the seven were changed to EXT. Throughout training, 30-sec TO periods occurred following each component presentation. Thus, if TO is like EXT in its effects, this means that the conditions immediately following the VI components were unchanged throughout the experiment. If contrast were due exclusively to the following-schedule effect, therefore, the magnitude of the contrast effect should be greatly reduced by the TOs being included in the procedure. Yet very robust contrast effects were obtained (although they were not compared with contrast effects obtained without TOs). The apparent implication is that contrast must be due to some variable other than the following-schedule effect.

One problem with interpreting the results of Rowe and Malone (1981) is that a comparable study has produced very different results. Mackintosh et al. (1972) used a between-group design in which two of the conditions had a VI schedule alternated with either 10-sec or 60-sec TOs. Two other conditions had the same VI schedule, again always preceded and followed by the same two TO values, but also interspersed with a second keylight associated with EXT. With the 10-sec TOs, the addition of the S— stimulus produced a substantial increase in response rate (i.e., contrast), but with the 60-sec TOs the addition of the S— stimulus had no effect. Moreover, the group with the 60-sec TO, without the S—, exhibited a response rate comparable to all groups with an S—, suggesting that the maximal amount of contrast had been produced by the 60-sec TO alone.

The results of Rowe and Malone (1981) also had two features that distinguish them from other contrast experiments. First, the response rates of their subjects were unusually high, with a mean over 200 responses/min. Second, several of their subjects developed high rates of responding during the TO periods (to the dark key) despite such responding never being reinforced. Given such differences and the conflict with the results of Mackintosh et al. (1972), it is unclear whether their results are idiosyncractic to some feature of their procedure, and thus the implication for the generality of the following-schedule effect is uncertain.

The conclusion supported by the preceding discussion is that the following-schedule effect is the major component of steady-state contrast. This is not to say other effects do not occur as well (e.g., local contrast), but such effects have been shown not to occur under at least some procedures. Nevertheless, an important issue for future research is the relationship between the different effects and how they combine to produce the molar properties of schedule interactions that have been reported when the different types of contrast have been lumped together (e.g., matching).

III. EVALUATION OF PREVIOUS THEORIES

A. Introduction

Explicit discussion of the various theories that have been proposed has been deferred until now because it seemed more appropriate to review the major empirical facts that any theory must explain. The plan for the ensuing discussion is to describe briefly each separate theory, its major claims, and the evidence that appears to support it. We then turn to the evidence that detracts from the particular theory and examine what modifications, if any, would make the theory encompass the counterevidence.

B. Additivity Theory

1. *The theory and its support*

As developed by Gamzu and Schwartz (1973), Hearst and Jenkins (1974), Rachlin (1973), and Schwartz and Gamzu (1977), additivity theory claims that contrast is due to the addition of elicited pecks to the operant baseline, with these elicited pecks controlled by the Pavlovian contingency between the keylight stimuli and the reinforcer. The implication is that contrast in multiple schedules has little to do with contrast and matching in concurrent schedules, since contrast in multiple schedules is mediated entirely by stimulus-reinforcer contingencies.

Three major sources of support for additivity theory have been cited: (1) Contrast occurs only in some situations, namely those where the discriminative stimuli are located on the response key; (2) the functional characteristics of contrast in conventional multiple schedules are paralleled by the occurrence of pecking in response-independent schedules in which presumably only the stimulus-reinforcer contingency is controlling the behavior; (3) the occurrence of signal-elicited pecks and operant pecks can be dissociated functionally by the "signal-key" procedure (cf. Keller, 1974), and when such a dissociation has been accomplished, only the signal-key pecks vary during a contrast manipulation.

2. *Reevaluation of the positive evidence*

The first set of evidence taken as support for additivity theory has already been discussed extensively in previous sections. Contrary to additivity theory, contrast has been demonstrated in a variety of situations in which the discriminative stimuli are located off the response manipulandum (e.g., Bradshaw et al., 1978). Such demonstrations are so numerous, in fact, that it would seem that they alone should be sufficient to undermine additivity theory as a viable explanation. However, the interpretation of such demonstrations must be tempered by the finding of Schwartz (1973) that a nonlocalized stimulus (a tone) can come to elicit key pecking in its own right. In his study, pigeons received response-independent food on a multiple VT EXT schedule, either with different colored keylights or tone vs. no tone as the discriminative stimuli. Key pecking (to a constantly illuminated key) initially did not develop during the tone stimulus but did occur after an intervening period of training when the keylight differentially associated with the VT component and the tone were presented together. Such pecking then continued to be elicited by the tone alone after the differential keylight signal was removed. A possible interpretation is that the tone had become a conditional stimulus, which instructed the subject that the constant keylight had different values depending upon whether the tone was present. Given that possibility, the implication is that the occurrence of contrast with nonlocalized stimuli cannot be taken as strong evidence against additivity theory. On the other hand, such a mechanism seems unlikely to account for the occurrence of contrast in the variety of different procedures where it has been demonstrated.

The parallel between the occurrence of contrast and the behavior that occurs under response-independent reinforcement schedules (multiple VT EXT) provides much more impressive evidence in favor of additivity theory. Such parallels are often quite striking, even when several different conditioning parameters have been varied (e.g., Schwartz, 1975, 1978a; Spealman, 1976). However, it is important to recognize that the parallels do not mean necessarily that signal-reinforcer contingencies are the source of contrast effects in multiple schedules. Like any correlation, the parallel between response-independent and response-dependent schedules may be due to either factor causing the other, or to some third variable that causes both. For example, it is possible that the parallels stem from response-reinforcer relations playing an important role in response-independent schedules. Williams and Heyneman (1981) have provided evidence that such is the case, since they found that the degree of pecking maintained by a multiple VT EXT schedule was greatly reduced if reinforcement was prevented within two seconds after the last peck. Such a finding strongly suggests that adventitious response-reinforcer pairings play a major role in maintaining "elicited" behavior (also see Davison, Sheldon, & Lobb, 1980). It is important to emphasize that one need not assume that all behavior maintained by a multiple VT EXT is due to adventitious reinforcement, but only that a significant part is. Even partial control by the "operant" contingencies would be sufficient to produce most of the parallels that have been reported.

The possibility of a third variable mediating the correlation between response-dependent and response-independent schedules also deserves serious consideration. This is especially true if it is recognized that contrast may involve changes in the value of the reinforcer itself. This is suggested by the results of Flaherty and Checke (1982), who showed that a contrast effect in the amount of consummatory saccharin licking could be produced by varying the concentration of sucrose that followed. Since contrast effects in consummatory behavior are often ascribed to changes in hedonic value, and since the following-schedule effect is a major cause of contrast in conventional multiple schedules, the implication is that all contrast may be mediated by changes in reinforcer value. If so, behavior controlled by any reinforcement contingency, whether stimulus reinforcer or response reinforcer, should be expected to be similar.

Finally, it is important to recognize that the effects of response-dependent and response-independent schedules are not parallel with respect to all variables. Williams (1981) has argued that a major difference between them is their sensitivity to molar reinforcement contingencies, independent of the local effects of the transitions between the components of the schedule. Williams (1976b) and Farley (1980a) used multicomponent response-independent schedules that allowed the separation of the effects of the preceding schedule, the effects of the following schedule, and the effects of overall differences in reinforcement probability, and found that all three variables played a significant role, with overall probability of reinforcement the most powerful. On the other hand, Williams (1981) used similar multicomponent response-dependent schedules and found that overall reinforcement probability played no independent role.

Differential effects of molar reinforcement probability should not be surprising when it is recognized that response-dependent and response-independent schedules may differ strongly with respect to the "signal-value" of the keylight during the nondifferential baseline. For a multiple VT VT, the keylight is no better a predictor of food than any other feature of the chamber, so that the change to multiple VT EXT produces a large increase in its relative predictiveness. During the multiple VI VI, on the other hand, the keylight is already differentially associated with food, since attention (and pecking) to any other feature of the chamber is never associated with food. Thus, the change to multiple VI EXT produces a much smaller increase in the relative predictiveness of the keylight.

The preceding argument assumes that response-reinforcer contingencies implicitly create stimulus-reinforcer contingencies. This argument has been developed in detail by Moore (1973), who argues that the differential reinforcement associated with different parts of the chamber should be functionally equivalent to that which occurs when different keylights are differentially correlated with food on a temporal basis. The ironic implication is that changes in the stimulus-reinforcer contingency cannot be used to explain contrast in response-dependent schedules, if signal-elicited pecking is generally assumed to play a major role in determining behavior. That is, the strength of the stimulus-reinforcer contingency created by the response requirement seems intuitively to be considerably stronger than that by the temporal contingency, so that the change from a multiple VI VI to multiple VI EXT should be associated with only a minor increase in the signal value of the keylight stimulus.

Perhaps the strongest evidence supporting additivity theory is that from the signal-key procedure, where the response requirement for both components of a multiple schedule is associated with one response key that has a constant stimulus, while the discriminative stimuli for the two components are located on a second key, which has no response requirement. Two aspects of the signal-key results have been taken as strong support for additivity theory: (1) Contrast does not occur when "operant" pecks are considered in isolation; and (2) the change from nondifferential reinforcement to differential reinforcement causes the development of responding to the signal key. These two effects together have led to the claim that the increase in responding in the usual contrast procedure, where the discriminative stimuli are located on the response key, is due to the addition of elicited pecks to the operant baseline.

Although the original findings with the signal-key procedure seemed to clarify the different determinants of responding in a multiple schedule, it is now apparent that the two generalizations just presented are oversimplifications. As discussed earlier (Section II.E-3), the failure to find operant-key contrast is most likely due to the confounding effects of changes in the response unit when nondifferential reinforcement is changed to differential reinforcement. As shown by Williams and Heyneman (1981), removal of such confounding does result in reliable contrast on the operant key. The significance of the development of signal-key pecking is similarly questionable, since Williams and Heyneman also demonstrated that signal-key pecking was greatly reduced by a 2-sec COD, where reinforcement for operant-key pecking was not allowed within 2 sec of the last signal-key peck. Thus, the response-reinforcer relation seems to play a major role in maintaining the signal-key pecking itself, so that the procedure cannot be taken as a valid method for dissociating elicited and operant behavior.

The fact that the COD procedure greatly reduces signal-key pecking does not imply that all such pecking is controlled by the response-reinforcer relation. It is likely that the stimulus-reinforcer relation also plays a significant role, particularly in view of the results of Woodruff (1979) that the type of peck to the signal varied as a function of whether food or water was used as the reinforcer. But such effects of the stimulus-reinforcer contingency do not imply that contrast effects depend upon the stimulus-reinforcer relation in any systematic way. An alternative interpretation is that the dynamics of elicited behavior are adjuncts to the dynamics of contrast, sometimes adding to the size of the contrast effect, sometimes interfering with it, and sometimes being completely independent. Woodruff's results in fact support this second interpretation, as he found reliable operant-key contrast with food as the reinforcer but no contrast (only induction) with water as the reinforcer. Yet in both cases pecking (although topographically different) did develop to the signal key. When such variability is coupled with the findings of Williams and Heyneman (1981) that operant-key contrast occurs reliably when changes in the response unit are controlled, the implication is that the signal-key results cannot be taken as serious evidence in favor of additivity theory.

3. *Evidence against additivity theory*

The numerous experiments showing reliable contrast with discriminative stimuli not located on the response manipulandum provide ample evidence against additivity theory, at least to the extent the theory requires motor behavior directed toward the discriminative stimuli. But some investigators (e.g., Woodruff, 1979) have suggested that this restriction on the type of behavior is too strong, as the stimulus-reinforcer contingency may control behavior other than that directed at the stimulus. But there is also contrary evidence, of a more conceptual nature, that argues against a necessary role for the stimulus-reinforcer contingency, regardless of the form of response controlled by that contingency.

One piece of counterevidence is provided by Zuriff (1970) and has been overlooked by previous theoretical discussion. Zuriff studied a multiple VI VR schedule, where the rate of reinforcement during one of the components was held constant while that during the other component was varied. Thus, VR reinforcement rate was held constant while VI reinforcement was varied, or vice versa. According to additivity theory, the two manipulations should have quite different effects on relative rate of responding, since two separate sources of pecking are assumed: operant pecks controlled by the response contingency and elicited pecks controlled by the stimulus contingency. Since the frequency of elicited pecks should be controlled by the stimulus-reinforcer contingency alone, equal changes in relative reinforcement in the two components should produce equal increments in the contribution of the elicited behavior. But because the operant rate maintained by the VR schedule is two to three times higher than that of the VI, the addition of equal amounts of elicited behavior should produce a smaller relative change in the VR rate. Thus, the function relating VR responding to relative rate of reinforcement should be considerably flatter than the function relating VI responding to relative rate of reinforcement. Contrary to this prediction, Zuriff (1970) found that variations in relative reinforcement had the same relative effect on the two components, with the VR response rate approximately two to three times greater than the VI response rate at every point on the function. Apparently, therefore, it is the operant unit that varies systematically with changes in relative rate of reinforcement.

A related piece of evidence against additivity theory is of a more logical nature. Namely, the theory provides no conceptual rationale for why matching should occur in multiple schedules. Rachlin (1973) addressed the issue by arguing that the relative contribution of elicited pecking became greater with shorter components, so that the relative rates of responding in a two-component schedule should diverge toward the relative rate of reinforcement as component duration was decreased. But such an account provides no reason for why matching should be the limit of the interaction. That is, if pecking on a multiple schedule is controlled by two separate sources, one that varies with component duration (elicited pecking) and one that does not (operant pecking), there is no reason why the sum of the two separate sources of pecking should vary so lawfully. Matching implies a 1:1 relationship between relative rate of responding and relative rate of reinforcement, which means that relative rate of reinforcement is a unitary variable, not one that can be decomposed into two separate effects.

Given the discussion of matching in Section II.C, it may be that this criticism is less serious than it first appears, since the generality of matching still is open to question. However, the data presented in Table 1 do make a meaningful case that matching is a real phenomenon, so that any theory that is logically incompatible with matching must be viewed with considerable reservation.

In summary, several different lines of evidence suggest that additivity theory should no longer be accepted as a viable explanation of contrast in multiple schedules. This conclusion is contrary to that of a recent review of additivity theory by McSweeney, Ettinger, and Norman (1981), who argued that a weak version of the theory is still not contradicted by the current evidence. McSweeney et al. may be correct in their assessment that no one experiment provides definitive evidence against additivity theory. However, the diversity of findings opposed to the theory leaves little doubt that it can be salvaged only by the postulation of a large number of post-hoc assumptions. But perhaps most importantly, none of the evidence that has been taken as strong support for additivity theory stands up to close scrutiny. Given the formidable problems faced by the theory, and the lack of any definitive evidence in its favor, it seems time to abandon it in favor of more promising alternatives.

C. Other Pavlovian-Process Theories

Additivity theory is only one of the ways that Pavlovian processes can be conceptualized as influencing behavior contrast. In fact it is quite restrictive in its stipulations, in that it requires that motor behavior be directed toward localized stimuli in the environment. The conceptualizations now to be discussed do not require that a Pavlovian CS elicit skeletal behavior, but rather only that it control a "central state," which is somehow a mediator of the increase in the operant response that constitutes behavioral contrast. Not surprisingly, these conceptualizations are less well developed than additivity theory and thus more difficult to disprove.

Gutman (1977) and Gutman and Maier (1978) have argued that contrast is due to the summation of two response processes, a Pavlovian process based on a differential stimulus-reinforcer association, and an operant process based on the response-reinforcer association. The major evidence supporting this position comes from Experiment 2b of Gutman and Maier (1978), in which a stimulus associated with the VT component of a multiple VT EXT was superimposed onto a VI operant baseline. The result was an enhancement of the operant response rate. Since diffuse stimuli were involved (a houselight or noise), autoshaped responses directed to the manipulandum cannot be used as an explanation of the enhancement. Thus, Gutman and Maier argued that the VT stimulus controlled an excitatory central state, and this central state combined with the operant factors to increase response rate.

Although the evidence provided by Gutman and Maier (1978) is of considerable interest, its relevance for a general theory of contrast becomes questionable when viewed in the context of research on positive conditioned suppression (cf. Azrin & Hake, 1969). By superimposing the VT cue of a multiple VT EXT on a VI baseline, Gutman and Maier approximated the positive conditioned suppression procedure, in which a CS terminating in free food is superimposed on a VI baseline. But unlike the results of Gutman and Maier, the CS is the latter procedure suppresses rather than enhances operant response rate. The results are not necessarily contradictory, however, since it is known that positive conditioned suppression depends upon the use of a relatively short CS, as response enhancement occurs when the CS is presented for longer durations (e.g., Meltzer & Brahlek, 1970; Meltzer & Hamm, 1978). Since the VT stimulus of Gutman and Maier was also presented for long durations, it is possible that their effect depends upon similar mechanisms. If that assumption is correct, it implies that the effects obtained by Gutman and Maier are restricted to a limited set of parameter values. Moreover, those values are just the opposite of those that produce maximal contrast in multiple schedules. That is, the work on positive conditioned suppression shows response enhancement only when long signals are presented, whereas contrast effects are larger with shorter component durations. It seems unlikely, therefore, that the central Pavlovian state invoked by Gutman and Maier can account for the contrast effects that normally occur.

The concept of an excitatory central state, as proposed by Gutman and Maier, should be distinguished from the use of Pavlovian principles by Malone (1976) to explain local contrast. He noted that the occurrence of local contrast followed the general principles cited by Pavlov for the occurrence of induction (the Pavlovian term for contrast), including (1) it occurs during the early stages of discrimination and disappears when the discrimination has stabilized, and (2) the magnitude of the effect depends on the similarity of the positive and negative stimuli, and if the similarity is very great, the effect may persist regardless of the amount of training. On the basis of such similarities, it seems likely that local contrast depends upon the same processes as those seen in other Pavlovian situations. In other words, local contrast at the onset of the S+ is a rebound effect of the removal of inhibition controlled by the just-prior S−. As noted earlier, however, local contrast is functionally independent of the effects of overall relative rate of reinforcement (cf. Farley, 1980a; Williams, 1976b, 1979, 1981, 1982). The implication is that the Pavlovian processes cited by Malone cannot provide a general explanation for contrast. This limitation is important because it implies that the mere demonstration of Pavlovian factors in contrast is not a sufficient reason for claiming Pavlovian processes as a general explanation. It is possible that many such effects are actually due to the local (and transitory) effects of "release from inhibition," and thus have little to do with the general effects of relative rate of reinforcement in steady-state situations.

D. BEHAVIORAL COMPETITION THEORY

1. *Development of the theory and supporting evidence*

Although response competition effects have received wide attention in the treatment of both simple and concurrent schedules (e.g., Rachlin, Kagel, & Battalio, 1980; Staddon, 1979), only recently has the notion been applied to multiple schedules (Henton & Iversen, 1978, pp. 229-245; Hinson & Staddon, 1978; McLean & White, in press; Staddon, 1982). The basic notion is that contrast in multiple schedules derives from the competition between interim and terminal behavior, both of which are produced by interval schedules of reinforcement (Staddon & Simmelhag, 1971). That is, during both components of a multiple VI VI schedule, both interim and terminal behavior occur and thus mutually compete. When the schedule is changed to multiple VI EXT, both types of behavior are eliminated in the EXT component. The interim behavior that did occur in the unchanged VI can then move into the EXT component, leaving more time for terminal responding in the unchanged VI, so that an increase in response rate (i.e., contrast) occurs. Thus, contrast in multiple schedules, like that in concurrent schedules, is due primarily to a change in time allocation, with a greater percentage of time devoted to terminal behavior (pecking) in a multiple VI EXT schedule than in a multiple VI VI (for the unaltered VI component).

The major evidence supporting the behavioral-competition hypothesis comes from Hinson and Staddon (1978), who found that the occurrence of contrast with rats as subjects was determined by the availability of other activities (also see Henton and Iversen, 1978, pp. 229-235, for a similar experiment). Hinson and Staddon compared two groups of rats that were trained initially to lever press on a multiple VI VI and then were shifted to a multiple VI EXT. The only difference was that one group had a running wheel in the experimental chamber. As shown in Figure 8, the major result was that rats with the running wheel available exhibited large, reliable contrast effects, whereas those without the running wheel showed small, unreliable effects. Most important, the occurrence of contrast in the former group was paralleled by a shift in location of the running behavior. During the multiple VI VI, equal amounts of running occurred in both components of the schedule, but after the shift to multiple VI EXT, virtually all of the running shifted to the EXT component. Thus, during the unchanged VI, the lever pressing no longer was reduced by competition from the running, so that the rate increase that is seen can be viewed as due to an increase in time allocation to the operant behavior.

Unfortunately, one aspect of the results of Hinson and Staddon makes the interpretation of their results equivocal. As can be seen from Figure 8, the two groups differed not only in the occurrence of contrast, but also in the degree of discrimination that was achieved. Since it is well known that the failure to demonstrate contrast is often associated with poor discrimination, the implication is that the running wheel may have had its effects indirectly, by increasing the discrimination, rather than directly via response competition. Thus, the group without the running wheel may have exhibited a similar degree of contrast had it been continued long enough to achieve a comparable discrimination performance.

Additional support for the behavioral-competition hypothesis comes from White (1978), who also studied the occurrence of contrast in rats. Different response levers, located on different sides of the chamber, were used for the two components of the schedule, so that White recorded the percentage of time allocated to one or other side of the chamber, in addition to the rate of lever pressing. The major finding was that contrast occurred for both measures but was more reliable with time allocation. Most important, when the local response rate was computed, there was no consistent effect of the contrast manipulations on local response rate. Thus, White argued that contrast is due to an increase in time allocation to the operant response, rather than an increase in the actual rate of response.

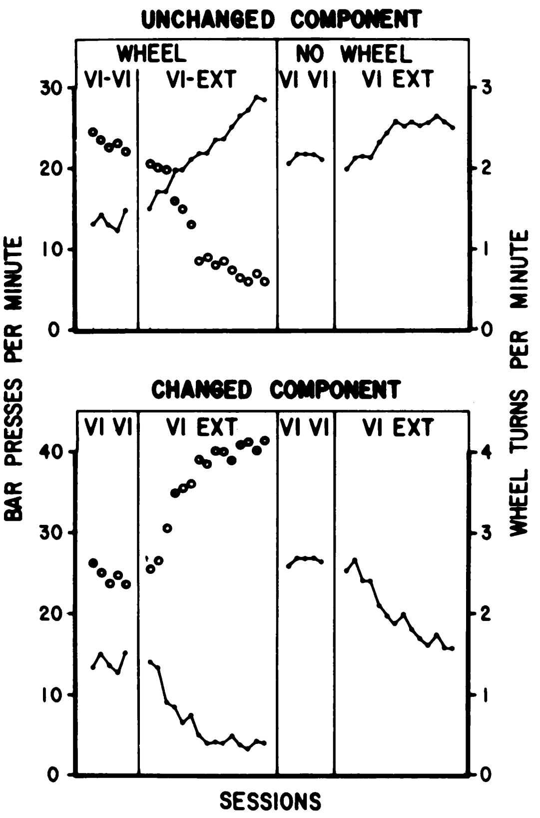

Fig. 8. Response rates from the contrast experiment of Hinson and Staddon (1978, their Figure 1). The top portion shows both lever pressing (the operant response) and wheel turning (unfilled circles) in the unchanged VI component. The bottom portion shows the corresponding results during the component that was changed from VI to EXT. The left side of each graph shows the results when the running wheel was available; the right portion shows the results when the wheel was removed.

Once again, however, there is reason to question whether the results actually support the behavioral-competition hypothesis. Although White did find more reliable contrast with time allocation, the actual magnitude of the effect was larger with the measure of response rate (i.e., the two measures differed greatly in variability). The difference in magnitude between the two measures must by necessity be due to differences in local response rate, which did increase under some conditions. Namely, local rate increased when multiple VI VI was changed to multiple VI EXT but then failed to decrease with the return to multiple VI VI. Thus, the nature of the data does not permit a strong conclusion about the presence of a contrast effect on local rate.

Still other supporting evidence comes from the analysis given by McLean and White (in press) discussed in Section II.B. They demonstrated that multiple schedules involving a concurrent schedule during both components of the multiple could be accurately described by a model (Equation 5) that assumed that choice within a component was the only mechanism producing the observed interactions. They then argued that the concurrent reinforcement that they explicitly scheduled was analogous to the reinforcement for behavior other than the operant response, which is normally available in the chamber. Thus, their model should also describe interactions in multiple schedules even without the concurrent schedules.

Although the fits of the data provided by the model of McLean and White are impressive, it is important to recognize that their model says nothing specifically about contrast effects. In order for their formulation to explain contrast, it is necessary to add the assumption that the activities competing with the operant response vary between components in the degree to which they provide competition. And since their data provide no direct evidence for such variation, their model can be taken only as indirect support for the behavioral-competition interpretation.

2. *The relationship between contrast and matching*

Staddon's (1982) development of behavioral-competition theory differs from that of McLean and White in his assumption that the total amount of behavior in a session is constant, and that the matching law applies, in principle, to the distribution of behavior over the session. Thus, if B_x, B_y, and B_o represent the times allocated to operant behavior during the two components (x and y) and the "other" behavior available during both components, and R_x, R_y, and R_o represent the corresponding reinforcement rates, it should be the case that

$$\frac{B_x}{B_x + B_y + B_o} = \frac{R_x}{R_x + R_y + R_o} \qquad (8)$$

for behavior summed over the entire session. However, this cannot be true generally because of the time constraint that the individual components are available for only 50% of the available time. Thus, the value of the left side of the equation can never exceed .5, since that is the maximum period of time available for B_x to be emitted. The relevance of this constraint for understanding contrast can be seen by considering a multiple VI 60-sec VI 60-sec schedule in which R_o is assumed to vary among 20, 60, and 120 reinforcers/hour. Thus, during the baseline the predicted values of B_x that correspond to the different values of R_o are .43, .33, and .25. When the schedule in Component Y is then changed to extinction, contrast is predicted in all cases because R_y drops out of the right side of the expression. The corresponding predicted values of B_x during the contrast phase then become .75, .50, and .33. But because B_x can never exceed .5, the obtained values of B_x should be .50, .50, and .33. Thus, by comparing the values of B_x during the baseline and contrast phases, it becomes evident that the largest difference (the magnitude of the contrast effect) occurs in the intermediate case. More generally, Staddon argues that obtained values of B_x increase with R_o until

$$\frac{R_x}{R_x + R_o} \leqslant .5$$

and are attenuated thereafter by time constraints. Thus, the maximum magitude of contrast occurs when $R_x = R_o$.

Staddon's formulation also predicts that the approximation to matching for $R_x/R_x + R_y$ will depend upon R_o but governed by a different function. That is, the approximation to matching increases as R_o becomes larger and reaches its maximum when $R_o \geqslant (R_x - R_y)$. Since his treatment of matching is similar to that of McLean and White (in press), it will not be discussed further.

3. *Effects of component duration*

Staddon's (1982) account of contrast and matching depends primarily on the combination of the matching law and the time constraints imposed by the fact that each component of a multiple schedule is available for only 50% of the time. His predictions are thus based on the static properties of the schedule and not the dynamic properties of R_o that are suggested by the results of Hinson and Staddon (1978). But the fact that contrast is affected profoundly by component duration implies that the dynamic properties of the schedule must be considered. To incorporate these effects, Staddon postulated the occurrence of momentary satiation/deprivation effects in the value of R_o. Thus, in a multiple schedule in which the reinforcement schedules are unequal, B_o will occur less frequently in the higher-valued component because of the greater competition from the operant response. This means that the value of R_o will increase the longer the time into the higher-valued component because of the momentary deprivation. Similarly, B_o will be relatively more frequent in the lower-valued component, so R_o should decrease with time into that component because of momentary satiation. The implications of these effects are shown in Figure 9 (Figure 5 of Staddon, 1982). In the top portion are the values of the constant reinforcement schedules in the two components. Depicted in the middle portion are the changing values of R_o, with the bottom portion then showing the actual behavior that results from competition between the operant responses and B_o. As can be seen, the maximum value of R_o is at the beginning of the lower-valued component, and the minimum value occurs at the beginning of the higher-density component.

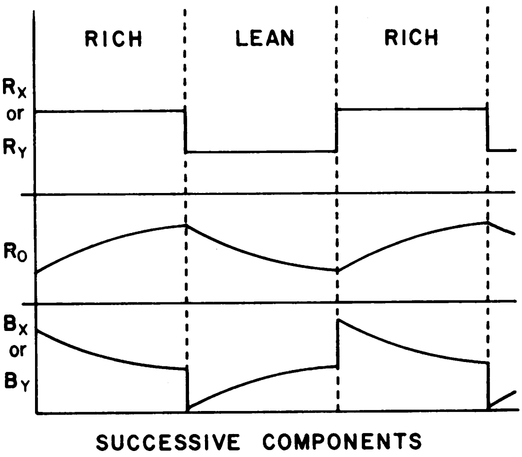

Fig. 9. Depiction of the hypothetical values of the operant reinforcement (top) and reinforcement for "other" behavior (middle), and the hypothetical levels of operant behavior (bottom) that result from their competition (taken from Staddon, 1982, his Figure 5). The operant schedules are assumed to be constant in value within a component but differ between components. The "value" of the other behavior is a function of the amount of momentary satiation/deprivation, which is a function of the competition from the operant response. Time is represented along the abscissa.

The effects depicted in Figure 9 are related to the effects of component duration in terms of how component duration affects the value of R_0. With short components, R_0 is approximately constant in the two components because there is little time for momentary satiation/deprivation to occur. Since the constancy of R_0 was a necessary assumption for Staddon's derivation of matching in multiple schedules, the implication is that matching should occur only with short components.

In fact, however, Staddon's analysis does not explain the critical effects of component duration. The patterns shown in Figure 9 do account for the fact that local contrast is more evident with longer components (Hinson & Staddon, 1981), but the finding of major interest concerns not local rate but average rate. That is, the average rates in the two components increasingly diverge the shorter the components, as response rate in the higher-valued component increases while that in the lower-valued component decreases (cf. Shimp & Wheatley, 1971). According to Staddon's analysis, such changes should depend on corresponding changes in the value of R_0. Thus, some explanation is needed for how a different average value of R_0 can occur, which changes in opposite directions in the two components of the schedule as component duration is varied. The functions shown in Figure 9 provide no such explanation, as it is evident that the average value of R_0 will always be the same in the two components whenever the satiation and deprivation functions are the same shape. Thus, without additional assumptions, Staddon's analysis does not explain the critical findings.

4. *Negative evidence*

Although the evidence just discussed in favor of behavior competition theory is encouraging, it faces one fundamental problem. Namely, if contrast occurs because of competition for the available time, the outcome of that competition should depend upon the frequency of responding in the altered component, not the frequency of reinforcement. But as shown earlier in Figure 1, the actual schedule in the altered component seems largely irrelevant, as the controlling variable is the relative rate of reinforcement. This is exemplified best when a multiple VI VT schedule is changed to multiple VI EXT. Since there is no operant response required in the VT component, this means that there is no operant response to provide competition with the interim responses during the baseline. Thus, the interim responses generated in the VI component could move into the VT component, even during the baseline, so that the operant rate during the VI of a multiple VI VT should be higher than the corresponding rate of a multiple VI VI. Further, when the VT is changed to EXT, there should be little change in the degree of competition in the altered component, so there should also be little change in the response rate in the unaltered VI. Thus, contrast effects with a multiple VI VT should be substantially smaller than contrast with a multiple VI VI. To the contrary, however, interactions with the two schedules appear to be basically similar.

Staddon (1982) has recognized this problem and has conceded that it is a problem faced by any account of multiple schedules based on the matching law as a general framework. But he has also argued that the response contingency may be irrelevant to the amount of operant behavior (or "terminal behavior") that occurs, since previous work has indicated that the rate of key pecking by pigeons is similar regardless of the presence of a response contingency (cf. Staddon & Simmelhag, 1971). He thus assumes that the frequency of operant responding is necessarily correlated with the frequency of reinforcement, regardless of the constraints imposed by the particular type of schedule.

But there are at least two reasons for questioning Staddon's argument. The first is that the generality of his claim of the response contingency being irrelevant is suspect, since Fenner (1980) reported major differences in the "superstition" procedure as a function of the presence of a response contingency. The second comes from the results of a recent study of signaled reinforcement. Williams (1980) presented pigeons with a two-component multiple schedule in which the schedule in one component was always VI 3-min, while that in the other varied among EXT, VI 1-min, or signaled VI 1-min. All three schedules were presented with three different component durations, ranging from 15 to 300 seconds. Figure 10 shows the results of the different conditions, averaged over subjects. The critical finding is that the response rate in the constant VI-3 component was the same when the VI-1 and signaled VI-1 were in effect, both of which differed from the EXT condition. Because response rate in the signaled component was itself very similar to that during EXT, the implication is that responding in the variable component does not predict the interactions that were obtained.

Staddon has argued that the results seen in Figure 10 are not convincing evidence against the behavioral-competition hypothesis because a signaled VI schedule may be like a VT schedule in terms of generating operant behavior that occurs independent of pecking the response key. Thus, the unmeasured behavior could provide the dynamics of competition in the same way as does key pecking in an unsignaled VI. The problem with this argument is that there is no differential effect for key pecks vs. any other type of operant behavior when the signal is absent. That is, all behavior is nonreinforced when the signal is absent, so whatever mechanisms discourage key pecking in the absence of the signal also should discourage any other operant (terminal) behavior. And since only key pecking is reinforced when the signal is present, to argue that behavior other than key pecking is maintained in the absence of the signal is to appeal to some as yet unknown principle of behavior. Thus, the effectiveness of the signaled contingency in eliminating key pecking should be taken as a reliable index of a systematic difference between the VI and signaled VI conditions in the level of operant behavior. And since the outcome of the competition between interim and operant behavior should be sensitive to such differences, the strong similarity in results produced by the two schedules, seen in Figure 10, must be taken as serious evidence against the behavioral-competition hypothesis.

A second type of contrary evidence comes from data showing that steady-state contrast is primarily an anticipatory effect, due to variations in the following schedule of reinforcement. Behavioral-competition theory implies the opposite, because of the momentary deprivation/satiation effects invoked by Staddon (1982) to account for the major functional properties of contrast (e.g., effects of component duration). Accordingly, the presumed mechanism of contrast is the carryover of interim behavior generated in one component to the succeeding component. Thus, variation in the rate of reinforcement in the preceding

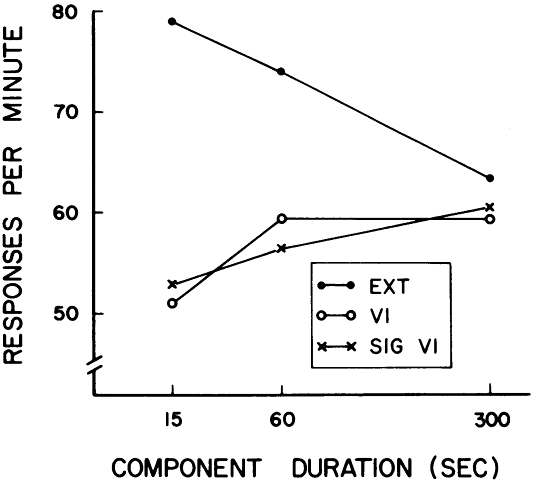

Fig. 10. Results from a two-component schedule, taken from Williams (1980, his Figure 1). The results are the means of four subjects for responding during the unchanged VI 3-min component, with the schedule during the other component either VI 1-min, signaled VI 1-min, or EXT (each shown by a separate function). All conditions were run under three different component durations.

component, not the following component, should be the condition that best produces contrast, a prediction that recent data contradict (Williams, 1976a, 1979, 1981).

E. The Relative Law of Effect

1. *Herrnstein's formula and its modification*

The last theoretical account of contrast to be considered is that of Herrnstein (1970), which focused on the "context of reinforcement." According to Herrnstein, relative rate of reinforcement determines behavior in simple schedules, multiple schedules, and concurrent schedules, all of which can be described by Equation 9:

$$B_1 = k\frac{R_1}{R_1 + mR_2 + R_o}, \qquad (9)$$

where B_1 represents the rate of behavior, R_1 the rate of reinforcement for that behavior, R_2 the rate of reinforcement for behavior under some other schedule, R_0 the rate of reinforcement for behavior not under control of the experimenter, and m the degree of interaction between the different schedule components (going from 0 to 1.0). The denominator of Equation 9 represents the context of reward in which a reinforcement event occurs, and the response-strengthening effect of that event is inversely related to the value of that context.

The aspect of Equation 9 that is most relevant to an account of contrast is the parameter m, which is assumed to vary with component duration. Thus, with short components, Equation 9 implies that the context of reinforcement will be determined increasingly by the schedule of the alternately presented component of the multiple, and in the limiting case with very short components, the context of reinforcement becomes functionally equivalent to a concurrent schedule. Thus, the empirical finding that matching occurs with short components (Shimp & Wheatley, 1971) seems to provide very strong support for Herrnstein's account. Additional evidence that has been taken as support comes from the effects of food deprivation on multiple schedule interactions (Herrnstein & Loveland, 1974) and from the effects of adding extra reinforcement to the situation (Nevin, 1974b; also see discussion by Herrnstein, 1970, pp. 261-265). However, both of these are perhaps better explained by the interpretation given by McLean and White (in press).

In spite of its ability to account for a variety of different findings, Equation 9 also makes several incorrect predictions, as noted by several investigators (de Villiers, 1977; Edmon, 1978; McSweeney, 1980; McSweeney & Dericco, 1976; Spealman & Gollub, 1974). Perhaps the most serious is that the equation predicts that response rates should decrease with shorter components for both components of the schedule, whereas in fact the response rate in the component with the higher reinforcement rate typically increases. A second problem is that Equation 9 predicts that there should be no contrast after a transition from a simple VI to a multiple VI EXT schedule, and conversely, that there should be a rate decrease when a simple VI is changed to a multiple VI VI with equal reinforcement rates. The reason for both of these predictions is that any increase in the denominator of Equation 9 (either by increasing m or by increasing R_2) should decrease the response rate.

One simple method for ameliorating these problems is to change the expression for the context of reinforcement to represent the average rate of reinforcement in the situation, rather than the sum of reinforcement rates. Equation 10 provides such a modification. The terms of the equation represent the same as Equation 9 with the exception that k no longer represents the maximum rate of responding:

$$B_1 = k\frac{R_1}{\dfrac{R_1 + mR_2}{1 + m} + R_o}. \qquad (10)$$

To see how Equation 10 captures the average rate of reinforcement, it is helpful to consider the effects of different values for m. If $m = 1.0$, reinforcement in both components is weighted equally in determining the average, so the first term of the denominator simply represents the average rate of reinforcement in a session. But all reinforcers cannot be weighted equally, given the decreasing magnitude of contrast effects when component duration is increased. Thus, with very long component durations the rate of reinforcement in the alternate components has little role in determining the average. The relative weights of the prevailing component vs. the alternate component in determining the average is thus the ratio $1/m$, where once again m is assumed to vary inversely with component duration.

To see the advantages of this modification, consider the two criticisms of Equation 9 that were noted above. For the case when a simple VI is changed to multiple VI EXT, Equation 10 does predict contrast because the denominator of the expression decreases when the EXT component is added. For the case of decreasing component duration, where m is increased, the prediction is more complicated because it depends on the relative values of the two components. Whereas Equation 9 implies that response rate should always decrease when m increases, Equation 10 predicts an increase in rate when R_1 is larger than R_2 and a decrease in rate when R_1 is less than R_2. Since these are the typical results, the implication is that the simple modification of Herrnstein's formulation embodied in Equation 10 can account for much of the data that previously have been regarded as counterevidence.

One problem that remains even with Equation 10 is the effect of absolute rate of reinforcement on the magnitude of contrast. As noted by Spealman and Gollub (1974) and McLean and White (in press), Equation 9 predicts that contrast should be greater the higher the rate of reinforcement, and this is true for Equation 10 as well. Contrary to this prediction, Spealman and Gollub reported that contrast was greater with leaner schedules of reinforcement, both in absolute and relative terms.

Although the results of Spealman and Gollub might be handled by postulating an interaction between reinforcement density and intercomponent generalization (i.e., the higher the rate of reinforcement in one component, the more its effects generalize to the second component), the analysis given by McLean and White (in press) and by Staddon (1982) suggests that the effect is more fundamental in its implications. They argue that the critical determinant of multiple schedule interactions is the relative values of R_1 vs. R_0 (see Equation 5 in Section II.B), because choice between the operant behavior and the "other" behavior is the mechanism by which interactions are mediated. As will be seen in the next section, however, whether choice is the mechanism depends critically on the interpretation of R_0 as reinforcement from sources other than the operant response, and this interpretation is now open to serious challenge.

2. *Inhibition by reinforcement: A primordial effect?*

To see how the role of context of reinforcement might be conceptualized differently, it is first necessary to consider Herrnstein's account of response rate in single-response situations (Equation 11):

$$B_1 = k\frac{R_1}{R_1 + R_0}. \tag{11}$$

Its conceptual rationale is that k represents the total amount of behavior possible in the situation, so that the reinforcement contingent on B_1 exerts its effects by determining the proportion of the total behavior that is allotted to B_1, in accordance with its proportion of the total reinforcement in the situation. Thus, R_0 refers to the sources of reinforcement other than that contingent on the operant response and is inferred after the fact.

Although Equation 11 successfully describes the relationship between responding and reinforcement in a single schedule situation, Herrnstein's conceptual rationale for the equation now seems questionable. Other investigators (Catania, 1973; Killeen, 1982; Staddon, 1977) have derived Equation 11 from different theoretical perspectives with the result that the two parameters have very different interpretations. Catania's development of the equation will be considered in detail because its extension to multiple schedules is relatively straightforward.

According to Catania (1973), responding maintained by a simple VI schedule is controlled by two separate effects, an excitatory effect, described by Equation 12, which is directly proportional to the rate of reinforcement:

$$B_{E_1} = kR_1 \tag{12}$$

and an inhibitory effect, described by Equation 13, which also increases with rate of reinforcement:

$$B_{I_1} = \frac{1}{1 + \frac{R_1}{C}}. \tag{13}$$

Note that k in Equation 12 is simply a scale parameter, whereas C, which is analogous to R_0 in Equation 11, is a "constant of inhibition." Catania then assumes that the two effects interact multiplicatively to determine the actual response rate, with Equation 14 as the result:

$$B_1 = kC \frac{R_1}{R_1 + C}. \qquad (14)$$

Note that the only differences between Equations 11 and 14 is that k of Equation 11 is replaced by kC in Equation 14. Since k and C are both constants, it is possible to replace their product by a new constant, which makes the two equations identical. However the distinction is important because it allows an empirical test of the two accounts. That is, Herrnstein assumes that the values of k and R_0 are independent, whereas Catania's account implies that they are correlated (for Equation 11). As noted by Staddon (1977) and Killeen (1982), high correlations in fact do appear to be the case. The implication is that k of Herrnstein's general formula should not be regarded as representing the total amount of activity, which is the cardinal assumption underlying his extension of the matching law to single-schedule situations. And since that assumption is also critical to extensions of the matching law to multiple schedules (note that Herrnstein's interpretation of k is shared by McLean & White, in press, and Staddon, 1982), an account of multiple schedule interactions based on a different conceptual rationale seems required.

Catania's (1973) analysis may be extended to multiple schedules by the additional assumption that the inhibitory effects of reinforcement are proportional to the average rate of reinforcement in the situation, not just the reinforcement occurring during a particular component of the multiple. But as noted in the discussion of Equation 10, the reinforcement in the prevailing and alternate components may not be equal in determining the average, so that a weighted average may be necessary. Thus, Catania's Equation 13 would be modified to become Equation 15:

$$B_{I_1} = \frac{1}{1 + \frac{R_x}{C}} = \frac{1}{1 + \frac{\frac{R_1 + mR_2}{1 + m}}{C}}. \qquad (15)$$

Assuming that the excitatory effects of reinforcement are governed only by the reinforcement contingent on the particular response, Equation 12 should still describe such effects, so that the product of the excitatory and inhibitory effects yields Equation 16, which is identical to Equation 10 with the exception that kC has replaced k:

$$B_1 = kC \frac{R_1}{\frac{R_1 + mR_2}{1 + m} + C}. \qquad (16)$$

This implication is that the context of reinforcement still should determine multiple schedule behavior, quite independent of the matching law on which Herrnstein's account was initially based.

A major reason for preserving the concept of "context of reinforcement" is that some such notion seems demanded by major developments outside the multiple schedule literature. Gibbon (1977) has proposed a choice model that has as its fundamental assumption that the subject evaluates the momentary rate of reinforcement against the average rate in the situation. More recently, this model has been extended to an account of autoshaping (Gibbon, 1981; Gibbon & Balsam, 1981). From a different perspective, Fantino (1977) has summarized the evidence supporting his delay-reduction formulation for choice in concurrent-chain schedules, which has a similar basic assumption. Namely, the effectiveness of a stimulus as a conditioned reinforcer is a function of its average time to reinforcement, compared to the average time to reinforcement (the inverse of rate) in the situation as a whole. The considerable success of such formulations, and their independent development, suggests that reinforcement is inherently relativistic in its effects, regardless of the particular conditioning preparation that is studied. Equation 16 thus gains at least indirect support, since it provides a method for applying that concept to behavior in multiple schedules.

3. *The relationship between multiple and concurrent schedules*

A central feature of Herrnstein's (1970) analysis was its claim that interactions in multiple and concurrent schedules are fundamentally similar. The fact that matching occurs for both schedules appears to provide continued support for this contention. However, there are now good reasons for doubting whether schedule interactions in the two situations involve the same mechanisms. Already noted in the preceding section was the problem in interpreting Herrnstein's description of single-schedule behavior (Equation 11), as there is now substantial reason to doubt whether such behavior has anything to do with the generalized matching law. If such doubts prove well founded, it is likely that behavior in multiple schedules is also independent of the matching law, since multiple schedules are more similar to simple schedules than to concurrent schedules.

A related reason for skepticism about the similarity between the two schedules has come from recent research on the mechanism of matching in concurrent schedules. Instead of relative rate of reinforcement being regarded as a primitive variable, choice in concurrent schedules has been ascribed to the process of "melioration," by which the animal responds to equalize the reinforcement rates for each response alternative, with rate of reinforcement calculated on the basis of time spent responding on an alternative (Herrnstein & Vaughan, 1980; also see Rachlin, 1973). Since such a process seems unlikely to be extendable to multiple schedules because the experimenter controls access to each component, the implication is that different mechanisms are involved for the two situations.

There is by no means general agreement about the best account of choice in concurrent schedules. For example, Herrnstein's account in terms of melioration is challenged by data showing that response rate for one alternative in a concurrent schedule is a function of the reinforcement rate associated with the second component, not the amount of responding required to produce that reinforcement (Catania, 1963). Nevertheless, understanding the relationship between multiple and concurrent schedules may be advanced by distinguishing between effects on response allocation (choice) and effects on the absolute response rate. As suggested by Catania (1973), increasing the reinforcement rate for one alternative of a schedule may have two separate effects. First, it will increase the response strength of that alternative relative to the second alternative, which in turn determines the allocation of the total behavior according to a choice rule that remains to be determined. Second, it also will increase the total context of reinforcement, which produces inhibition of all responding in the situation. Given such a separation, it may be that interactions in multiple schedules involve only this second effect, whereas those in concurrent schedules involve both. The implication is that "choice" accounts of concurrent behavior such as Herrnstein and Vaughan's melioration, or the momentary maximizing of Shimp (1966) and Silberberg, Hamilton, Ziriax, and Casey (1978) may be correct but incomplete. What is lacking in such formulations is an account of how context of reinforcement affects the absolute rate of responding, which is also the mechanism that generates the similarities between multiple and concurrent schedules that have been demonstrated.

4. *The problem of temporal asymmetry*

A major empirical obstacle faced by Equation 16 is that steady-state interactions in multiple schedules are temporally asymmetric in character. Recent data (see Section II.F) have shown that variation in the reinforcement schedule that precedes a target component has little consistent effect, but variation in the following schedule has a major effect. Most important, there is no good evidence of any effect of molar relative rate of reinforcement independent of the following schedule of reinforcement (cf. Williams, 1981). Given the asymmetry, some modification of Equation 16 is clearly needed. Equation 17 provides one possibility, as it allows the effective context of reinforcement to be a weighted average of the prevailing component, the following component ($n+1$), and the preceding component ($n-1$), where different weights are possible for all three sources of reinforcement:

$$B_n = kC \frac{R_n}{\frac{R_n + fR_{n+1} + pR_{n-1}}{1+f+p} + C}. \quad (17)$$

Preliminary data from an unpublished experiment involving a three-component multiple schedule in fact suggest that Equation 17 provides an excellent description of both absolute and relative response rates. But the issue is not merely whether the data can be described by a variation of a quantitative formula. It is also whether a theoretical rationale can be developed for why the temporal asymmetry occurs. The fate of that issue, perhaps more than any other, will determine the status of relative rate of reinforcement as the single, general determinant of schedule interactions.

IV. CONCLUSIONS

The major generalization that can be drawn from the preceding review is that none of the previous theories of contrast can account for all of the available data. At the very least, a two-factor theory of contrast seems required: (1) an effect of Pavlovian contingencies, particularly as expressed as an excitatory rebound effect of removing an inhibitory stimulus, and (2) a general effect of relative rate of reinforcement. The distinction between these two effects is based on several different functional properties, as the Pavlovian effect is usually transitory and stimulus-dependent, whereas the general effect of relative rate of reinforcement occurs in steady-state situations and is stimulus-independent. But it also should be remembered that these two effects may not be completely independent, since there is evidence that the Pavlovian effect itself depends on the relative value of the preceding stimulus; it is not an inhibitory effect independent of the context (cf. Malone & Staddon, 1973).

An additional caveat is that the two major effects that have been cited do not exhaust those that occur in multiple schedules. It seems likely that stimulus-elicited behavior plays a role in at least some situations (e.g., Woodruff, 1979), although I have argued that such effects are more likely to detract from schedule interactions than to enhance them and certainly are not as important as implied by additivity theory. Still other variables that may produce schedule interactions are changes in response topography and changes in the spatial location of the controlling stimulus. In addition, there is some evidence that contrast may occur even in mixed schedules as a result of the dynamics of "behavioral conservation" (Allison, 1976). All in all, therefore, contrast is a multiple-determined phenomenon, where several different variables may operate simultaneously in any particular situation.

But the complexity of contrast should not be allowed to obscure the regularities that have been discovered. When steady-state interactions are studied intensively, a strong case can be made that there is a single dominant effect, controlled primarily by the relative rate of reinforcement. But how relative rate of reinforcement should be conceptualized is not a settled issue, as the best-known formulation (Herrnstein, 1970) has been shown to have several deficiencies. But it is possible to make a simple modification of Herrnstein's formulation that accounts for most of the discrepant data by proposing that the response rate maintained by a given schedule of reinforcement is inversely related to the average rate of reinforcement prevailing in the situation. Such a change is provocative, because it implies that the independent variable controlling contrast is essentially like that formulated for conditioning effects in other situations, notably conditioned reinforcement and autoshaping (Fantino, 1977; Gibbon, 1981). If this similarity proves more than superficial, the implication is that a common, general, relativistic principle of reinforcement cuts across highly diverse procedures and phenomena.

But there are also reasons to doubt whether relative rate of reinforcement is properly conceptualized as a molar variable. Schedule interactions are temporally asymmetrical in that the effects of context of reinforcement are primarily anticipatory in character. At present there is no rationale for this asymmetry, so that any strong theoretical claim should be held in abeyance until that issue is resolved.

A final caveat is that many of the findings that have been used to dissociate the various theoretical alternatives are still quite tentative in nature. In particular, the theoretically most important finding—matching in multiple schedules—still has not been shown to be a highly general phenomenon. Whether overmatching occurs, whether matching occurs with rats as subjects, and whether matching depends on the presence of other competing activities in the situation are all empirical issues that require further investigation before confident conclusions can be drawn. But such uncertainties should not obscure the regularities that have been found already. In recent years schedule interactions have been viewed as a quagmire of different effects, so that meaningful functional analysis has seemed impossible. The aim of the present review has been to show that this view has been overemphasized and that contrast effects remain as extremely important phenomena that tell us about the fundamental laws of behavior.

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