

# Behavioral contrast as a function of component duration and baseline rate of reinforcement

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Three experiments examined changes in size of multiple-schedule behavioral contrast with changes in an independent variable. Experiment 1 found that positive contrast generally increased with increases in component duration when pigeons pressed treadles. Experiments 2 and 3 found that positive and negative contrast generally increased with increases in the baseline rates of reinforcement when pigeons pecked keys. The experiments show that positive and negative contrast vary as similar functions of the same variables. Experiment 1 also suggests that these functions are different for different responses.

Behavioral contrast refers to an inverse relationship between the rate of responding during one component of a multiple schedule and the conditions of reinforcement in the other component. Positive contrast is an increase in responding during one component with a worsening of the conditions of reinforcement in the other component. Negative contrast is a decrease in responding with improvements in the other conditions of reinforcement. Positive and negative contrast may be measured relative to a baseline multiple schedule that provides the same, intermediate, rates of reinforcement in the two components (McSweeney & Norman, 1979).

Theories of multiple-schedule behavioral contrast have received much attention recently (e.g., McSweeney, Ettinger, & Norman, 1981; Williams, 1983). In spite of the attention, no one theory has emerged as the best description for contrast. In the absence of a theory, two fundamental questions about contrast remain unanswered. First, it is not known whether contrast occurs similarly for all responses. Second, it is not known whether positive and negative contrast vary as similar functions of the same variables.

Different theories take different positions on these questions. For example, Herrnstein's (1970) theory appears in Equation 1:

$$P_1 = \frac{kR_1}{R_1 + mR_2 + R_0} \quad (1)$$

$P_1$  is the rate of responding emitted during one component of the multiple schedule for a rate of reinforcement equal to  $R_1$ .  $R_2$  is the rate of reinforcement obtained from the other component. The parameters  $k$ ,  $m$ , and  $R_0$  represent the subject's asymptotic rate of responding, the

degree of interaction between the components of the multiple schedule, and the rate of reinforcement obtained from unprogrammed sources, respectively. Contrast is a change in the rate of responding in one component ( $P_1$ ), which occurs when the rate of reinforcement obtained from the other component changes ( $R_2$ ).

Herrnstein's theory predicts that contrast should occur similarly for all responses. Contrast occurs whenever the rate of reinforcement in the second component changes regardless of what response produces it. Therefore, contrast should occur similarly for all responses.

Positive and negative contrast should also vary as similar functions of the same variables. Increases in  $R_2$  should produce decreases in  $P_1$  (negative contrast). Decreases in  $R_2$  should produce increases in  $P_1$  (positive contrast). Therefore, positive and negative contrast should vary as the same function of the same variable.

Competition theory (Hinson & Staddon, 1978) agrees that contrast should occur similarly for all responses and that positive and negative contrast should be similar functions of the same variables. It argues that contrast results when competing responses reallocate from the constant, contrast, component of a multiple schedule to the variable component (positive contrast), or from the variable component to the contrast component (negative contrast). The reallocation of competing responses produces contrast as a result of disinhibition (positive) or inhibition (negative) of operant responding. According to this theory, contrast occurs whenever competition occurs, and therefore, contrast should occur for all responses. Positive contrast results from a decrease in competition, and negative contrast results from an increase in competition. Therefore, positive and negative contrast should be similar functions of the same variables.

The additive theories disagree (Gamzu & Schwartz, 1973; Hearst & Jenkins, 1974; Rachlin, 1973). Although these theories differ in detail, all argue that additive responses, controlled by the stimulus-reinforcer relation, are present during the component of a multiple schedule

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which provides the more favorable conditions of reinforcement. Rachlin also argues that additive responses are inhibited during the component that provides the less favorable conditions. Contrast occurs when additive responses facilitate (positive contrast) or suppress (negative contrast) the instrumental responses.

The additive theories argue that contrast will not occur similarly for all responses. Contrast will occur only when the additive responses take a form that interacts properly with the instrumental response (e.g., Rachlin, 1973). Schwartz (1975) also argued that his version of this theory did not apply to negative contrast. Therefore, positive and negative contrast are not necessarily produced by similar variables.

One reason for the present inability to determine whether contrast occurs similarly for all responses and whether positive and negative contrast occur under similar circumstances may be that past experiments have usually asked only whether contrast occurs or does not occur under specific conditions. They have not studied functional changes in the size of contrast with changes in an independent variable. For example, past studies have examined contrast for different responses by asking whether contrast occurs under similar conditions for all responses. Several studies failed to produce positive contrast when pigeons pressed treadles under circumstances that did produce it when they pecked keys (Hemmes, 1973; McSweeney, 1978; Westbrook, 1973). Experiments examining the symmetry of positive and negative contrast have asked whether some conditions produce positive contrast without producing negative contrast, and vice versa. Some have found one type of contrast under circumstances that did not produce the other (e.g., Ettinger & McSweeney, 1981; McSweeney, 1978; Schwartz, 1975).

However, these experiments cannot unambiguously answer the present questions. Their failures to find contrast may always be attributable to procedural problems with the experiments rather than to fundamental differences between responses or between positive and negative contrast. For example, the failure to find positive contrast when pigeons press treadles has been attributed to the difficulty in detecting changes in the generally low rate of treadle pressing (e.g., Davison & Ferguson, 1978), to an insensitivity of treadle pressing to reinforcement (e.g., Staddon, 1982), and to poor discrimination between the components for treadle pressing. Without further information, it is difficult to dismiss these explanations for the differences between responses.

A better way to address these questions is to examine changes in the size of contrast as a function of several independent variables. Behaviors that change as similar functions of an independent variable could be reasonably attributed to similar theoretical mechanisms. Changes that show different functions might form the basis for arguing that different mechanisms were involved. As will become apparent in the discussion, finding different functions can also rule out many simple explanations for the

differences in results, and can provide a stringent test of the quantitative details of existing theories of contrast.

The present experiments addressed these questions by studying change in the size of contrast as a function of two variables. Experiment 1 examined changes in the size of positive contrast as a function of component duration for treadle pressing. Experiments 2 and 3 examined changes in positive and negative contrast as a function of baseline rates of reinforcement for keypecking.

## EXPERIMENT 1

Experiment 1 examined positive treadle-press contrast as a function of component duration for two reasons. First, McSweeney (1982) found that orderly functions related component duration to the size of positive and negative contrast for keypecking and negative contrast for treadle pressing. She did not study changes in the size of positive treadle-press contrast because positive contrast had not been observed for treadle pressing at that time. The one study that had reported it was fundamentally flawed (Bushnell & Weiss, 1980). Contrast was small, transient, or absent for some subjects. Furthermore, baseline rates of responding were not recovered after the contrast phase of the experiment. Therefore, behavioral contrast could not be distinguished from fluctuations in responding over time. However, McSweeney (1983) showed that, if very high rates of reinforcement are used, positive contrast occurs when pigeons press treadles.

Second, an examination of contrast as a function of component duration can test Ettinger and Staddon's (1982) dynamic satiation model of contrast. This model predicts that the size of contrast will decrease as component duration increases. Ettinger and Staddon argue that changes in the size of contrast are explained by dynamic changes in the competition of instrumental responses with other, interim, responses during the components. According to their argument for positive contrast, competing responses are satiated near the beginning of the contrast component. Therefore, instrumental responses compete well with the alternatives, yielding a high rate of instrumental responding. As time within the component passes, the instrumental responses satiate and the competing responses become stronger, resulting in a lower rate of instrumental responding. The change in instrumental responding appears as a decrease in the size of positive behavioral contrast with increases in component duration or time within the component.

### Method

**Subjects.** Three homing pigeons, maintained at approximately 85% of their free-feeding body weights, served as subjects. All three subjects had served in McSweeney's (1982) study and, thus, had had experience in pecking keys and pressing treadles for food reinforcers. The two other subjects used in that study had died. The present subjects were used in spite of their old age because the results were to be compared to those of McSweeney (1982).

**Apparatus.** The apparatus was the same as that used by McSweeney (1978, 1982, 1983). It was a standard three-key Grason-Stadler pigeon station, Model E6446C, enclosed in a Grason-

Stadler, Model E3125A-300, sound-attenuating chamber. Two floor treadles were added. Each treadle, a 5.2-cm-diam aluminum disk, was held in a resting position 2.6 cm above the floor by a strip of aluminum, which connected it to the wall containing the magazine. The aluminum strips were 7.7 cm long × 1 cm wide. They entered the wall containing the magazine 16.8 cm below each of the two outer response keys. The centers of the keys were located approximately 19 cm apart and 8 cm from one of the side walls of the apparatus. The treadles produced a brief feedback click when operated by a force greater than approximately 0.25 N applied to their centers. A houselight located in the upper right corner of the wall containing the magazine illuminated the chamber throughout the session. A fan masked noises from outside the chamber. Electromechanical equipment located in another room scheduled the experimental events.

**Procedure.** Because they had all had previous experience in pressing treadles (McSweeney, 1982), the subjects were placed directly on several series of the following three schedules: multiple variable interval 15-sec variable interval 15-sec (MULT VI 15-sec VI 15-sec), followed by MULT VI 15-sec extinction (ext) and then by MULT VI 15-sec VI 15-sec. The set of three schedules was conducted in that order for each of the following component durations, presented in the following, irregular, order: 1 min, 30 sec, 16 min, and 5 sec. A fifth component duration of 2 min was under study when another subject died.

The components of the multiple schedule alternated. Presses on one treadle produced reinforcers for one component; presses on the other produced reinforcers for the other component. Presses on a treadle were not recorded when its component was not available.

The constant, VI 15-sec, component was presented on the treadle located to the subject's left as it faced the experimental panel, for all component durations except 1 min. When responses to the left treadle were reinforced, a red light appeared on the response key located directly above the treadle. The other component was presented on the right treadle, and was signaled by the appearance of a white light on the response key located directly above it. A two-treadle procedure was used because McSweeney (1978) did not find contrast when using only one treadle but did find it when using two.

A 3-sec time-out was presented each time the components alternated. During the time-out, the keylights were extinguished and treadle presses were not recorded or reinforced. This time-out was

included to ensure that the time required to walk from one treadle to the other would not be included in the calculation of the size of contrast. If it were, it would distort the measure more for shorter than for longer components.

Reinforcers consisted of 5 sec of access to a magazine containing mixed grain. They were scheduled according to a 12-interval Flesher and Hoffman (1962) series. Responses were not recorded, and the keylight was extinguished during reinforcement.

Sessions terminated after 60 reinforcers had been presented for the MULT VI 15-sec VI 15-sec schedules, and after 30 reinforcers for the MULT VI 15-sec ext schedules. Sessions were conducted daily, five to six times per week. Schedules were not changed until all subjects reached a stability criterion. Responding was considered stable when the response rates emitted during the last five sessions for which a schedule was available fell within the range of response rates for the same schedule during the earlier sessions. Responding was considered to be stable for a multiple schedule only when the response rates emitted during both components were stable. An average of 47 sessions were conducted for each schedule.

**Results and Discussion**

Table 1 presents the mean rates of responding emitted during each component of each multiple schedule, calculated over the last five sessions for which each schedule was available. Rates were calculated by dividing the number of responses emitted during each component by the time during which that component was available. The time during which the magazine was presented was excluded from all calculations.

Figure 1 presents the size of positive behavioral contrast plotted as a function of component duration. Contrast was measured by the differences between the rates of responding during the VI 15-sec components of the MULT VI 15-sec ext schedules and the average rates of responding during the same, VI 15-sec, components of the surrounding MULT VI 15-sec VI 15-sec schedules. Response rates were taken from Table 1. Points above the horizontal line represent positive behavioral contrast.

**Table 1**  
Rates of Responding in Presses per Minute Emitted During Each Component of Each Multiple Schedule

Schedule	Subject 99		Subject 61		Subject 1413		Mean	
	VI 15 sec Comp.	Other Comp.	VI 15 sec Comp.	Other Comp.	VI 15 sec Comp.	Other Comp.	VI 15 sec Comp.	Other Comp.
1-min Components* Schedule								
VI 15 sec VI 15 sec	22.6	42.7	13.5	24.5	35.4	37.6	23.8	34.9
VI 15 sec ext	27.8	24.6	32.6	8.8	45.2	7.4	35.2	13.6
VI 15 sec VI 15 sec	23.8	47.8	14.8	24.7	27.6	32.1	22.1	34.9
30-sec Components Schedule								
VI 15 sec VI 15 sec	37.9	17.7	22.5	37.3	29.5	17.1	30.0	24.0
VI 15 sec ext	31.2	6.9	26.3	2.3	39.8	4.3	32.4	4.5
VI 15 sec VI 15 sec	29.3	27.1	29.0	29.7	28.8	18.3	29.0	25.0
16-min Components Schedule								
VI 15 sec VI 15 sec	22.8	27.0	31.2	13.0	26.7	28.0	26.9	22.7
VI 15 sec ext	35.6	5.7	38.4	0.1	34.2	5.7	36.1	3.8
VI 15 sec VI 15 sec	20.3	30.5	31.8	12.5	29.2	26.0	27.1	23.0
5-sec Components Schedule								
VI 15 sec VI 15 sec	21.8	21.8	27.3	20.4	28.1	17.8	25.7	20.0
VI 15 sec ext	23.6	4.7	26.6	9.6	23.9	8.3	24.7	7.5
VI 15 sec VI 15 sec	25.5	24.6	29.8	24.8	28.0	21.5	27.8	23.6

Note—Comp. = component. \*The results for the 1-min component were taken from McSweeney (1983).

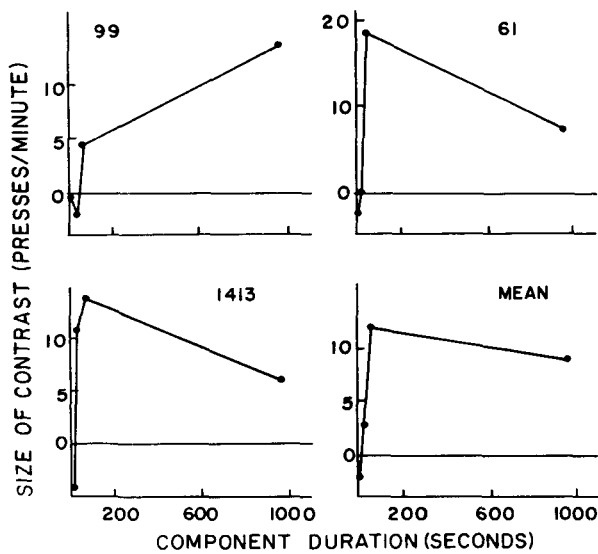


Figure 1. Positive contrast in presses per minute as a function of component duration, in seconds, for each subject and for the mean of all subjects in Experiment 1. Contrast was measured using the difference between the rate of responding emitted during the VI 15-sec component of the MULT VI 15-sec ext schedule and the mean rate of responding emitted during the comparable components of the MULT VI 15-sec schedules conducted for that component duration.

Points below the line indicate negative induction, defined as a decrease in the rate of responding during one component with decreases in the rate of reinforcement obtained from the other component.

Figure 1 shows that positive contrast occurred. Eight of 12 points for individual subjects, and 3 of 4 points for the mean of all subjects, fall above the horizontal line and, therefore, represent positive contrast.

The size of positive treadle-press contrast also varied with component duration. The size of contrast was shown, by *t* tests for matched pairs, to be significantly different ( $p < .05$ ) for the 5-sec versus 1-min component durations [ $t(2) = 2.92$ ] and for the 5-sec versus 16-min component durations [ $t(2) = 8.06$ ]. The size of contrast was also marginally significantly different for the 30-sec versus 16-min component durations [ $t(2) = 2.07, .05 < .05 < p < .10$ ].

The exact form of the function relating contrast to component duration is not clear. For one subject (No. 99), contrast increased with increases in component duration. For the other two subjects, it decreased at the longest component duration. The form of the function might have been clarified if more component durations had been studied. However, this was impossible because one of the subjects died during the experiment.

Regardless of the form of the functions, the present results contradict Ettinger and Staddon's dynamic satiation model. As argued earlier, the model predicts that the size of positive contrast will decrease with increases in component duration because instrumental responses sati-

ate and competing responses strengthen as time passes in the component. The present increases in the size of contrast with increases in component duration, at least up to a point, contradict this prediction.

Figure 2 compares the present results with those of McSweeney (1982). It displays changes in the sizes of both positive and negative contrast as a function of component duration for the mean of all subjects. Results are presented for keypecking (left side of the figure) and for treadle pressing (right side of the figure). The results for the mean generally represent the results for individual subjects.

Figure 2 shows that the absolute size of positive and negative contrast changed as similar functions of component duration for both responses. It also shows that these functions were different for keypecking and treadle pressing. For keypecking, the absolute size of both positive and negative contrast decreased as component duration increased. For treadle pressing, the absolute size of positive and negative contrast generally increased as component duration increased.

It seems unlikely that contrast would vary as different functions of an independent variable for keypecking and treadle pressing if the same theory accounted for both responses. Before rejecting a common theory, however, several procedural explanations for the differences in results should be studied. Because of the difficulty of

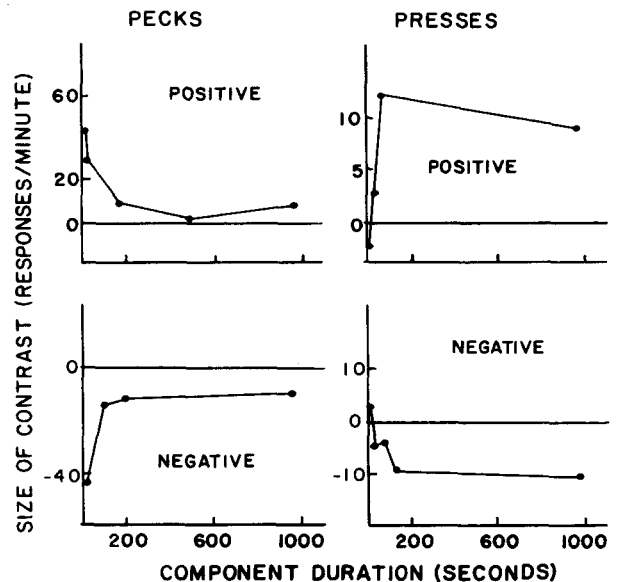


Figure 2. The size of positive and negative behavioral contrast as a function of component duration for the mean of all subjects responding in the present experiment and in McSweeney (1982). Results for keypecking are represented by the axes on the left side of the figure and are taken from McSweeney (1982). Results for treadle pressing appear on the right and are taken from the present experiment (positive contrast) and McSweeney (1982) (negative contrast). The size of contrast was measured as it was for Figure 1. [Parts of this figure are from McSweeney, F. K. (1982). Positive and negative contrast as a function of component duration for keypecking and treadle pressing. *Journal of the Experimental Analysis of Behavior*, 37, 281-293. Reprinted by permission.]

producing positive treadle-press contrast, the same procedure used to study keypecking in McSweeney (1982) could not be used to study treadle pressing here. Therefore, procedural factors may have produced some of the differences.

First, the present experiment used much higher rates of reinforcement than those used by McSweeney (1982) to study keypecking. Second, the present study and McSweeney (1982) used two operanda to study treadle pressing and a one-operandum procedure to study keypecking. Third, a time-out separated the components of the multiple schedule for treadle pressing, but no time-out was used when studying keypecking. Finally, the discriminative stimuli appeared directly on the response operandum for keypecking but not for treadle pressing.

It seems unlikely that differences in the rates of reinforcement used for the two responses explain the different functions. Different functions were also observed for negative contrast for keypecking and treadle pressing, even though McSweeney (1982) used similar rates of reinforcement to study both responses. However, none of these differences can be ruled out as explanations for the different functions. Positive keypeck contrast has not been examined at the high rates of reinforcement used here for treadle pressing. Another study, which also used a two-operandum procedure with a time-out between the components and discriminative stimuli which did not appear on the instrumental keys, should do this before common theories are rejected.

## EXPERIMENT 2

Experiment 1 and McSweeney (1982) showed that positive and negative contrast varied as symmetrical functions of component duration for keypecking and for treadle pressing. Experiments 2 and 3 investigated this symmetry as a function of another independent variable, baseline rate of reinforcement. As defined earlier, baseline schedules provide the same simple schedules of reinforcement in both components. Contrast is produced by changing the conditions of reinforcement provided by one of these components.

Changes in the size of contrast with changes in the baseline rate of reinforcement were studied for two reasons. First, they might provide information about whether contrast occurs similarly for all responses. Past results suggest that keypecking and treadle pressing may change as different functions of baseline reinforcement rates. Reynolds (1963) and Spealman and Gollub (1974) reported that positive keypeck contrast is easier to produce at lower rates of reinforcement (i.e., VI 3-min schedules) than it is at higher rates (i.e., VI 30- or 90-sec), perhaps suggesting that the size of keypeck contrast varies inversely with baseline rates of reinforcement. McSweeney (1983) reported positive treadle-press contrast at higher rates of reinforcement (e.g., a VI 15-sec schedule) than those used

in other studies (Hemmes, 1973; McSweeney, 1978; Westbrook, 1973), which failed to find contrast (e.g., VI 2-min schedules). This may suggest that the size of treadle-press contrast varies directly with the baseline rate of reinforcement.

Second, several theories predict how contrast should change with changes in the baseline rates of reinforcement. For example, the competition theory described earlier predicts that contrast should be largest for intermediate rates of reinforcement. According to this theory, contrast is small when rates of reinforcement are high, because operant responding occurs at such a high rate that it is influenced little by the reallocation of competing responses. Contrast is small also when rates of reinforcement are low, because few operant responses that need to be altered by the reallocation of interim responses occur. Sizable contrast occurs only when the competition between interim and operant behaviors is at its maximum, at intermediate rates of reinforcement. (See Staddon, 1982, for a formal derivation of this prediction.)

Herrnstein's (1970) theory (Equation 1) predicts that the size of contrast should vary directly with baseline rates of reinforcement. As long as  $k$  and  $m$  are not zero and all parameters remain constant across schedules, contrast should be larger for higher rates of reinforcement because the change in the size of  $R_2$  from the baseline to the contrast phase will be greater when  $R_2$  is a larger number.

The present experiments examined changes in the size of positive (Experiment 2) and negative (Experiment 3) contrast as a function of baseline rates of reinforcement for keypecking. Both types of contrast were produced by changing the baseline rate of reinforcement by a factor of two. This was done so that any changes in responding could be clearly attributed to changes in the baseline rates of reinforcement. If this had not been done, then any differences between positive and negative contrast, as well as any changes in the size of contrast, could be attributed to differences in the size of the change in the rates of reinforcement from the baseline to the contrast condition rather than to changes in the baseline rates of reinforcement per se.

For example, many authors have found that the size of positive contrast increases with the amount of decrease in the frequency of reinforcement associated with the changed component (e.g., Bloomfield, 1967; Nevin, 1968; Reynolds, 1963). If positive contrast were always produced by changing one component of the multiple schedule to extinction, then it might be argued that contrast was larger for higher rates of reinforcement because the change to the contrast phase was much larger for the higher rates of reinforcement. The difference between extinction and the approximately 240 reinforcers per hour provided by a VI 15-sec schedule would be much greater than the difference between extinction and the approximately 7.5 reinforcers per hour provided by a VI 8-min schedule. Changing the baseline rate of reinforcement by a constant ratio does not guarantee that the size of the

**Table 2**  
**The Schedules Conducted in Experiment 2, and the Number of Reinforcers Delivered per Session, in Order of Presentation**

Schedule	Number of Reinforcers
VI 1 min VI 1 min	40
VI 1 min VI 2 min	30
VI 1 min VI 1 min	40
VI 4 min VI 4 min	10
VI 4 min VI 8 min	6
VI 4 min VI 4 min	10
VI 30 sec VI 30 sec	60
VI 30 sec VI 1 min	50
VI 30 sec VI 30 sec	60
VI 15 sec VI 15 sec	60
VI 15 sec VI 30 sec	50
VI 15 sec VI 15 sec	60

change will be the same for all schedules, but it does the best that can be done in the absence of a scale of reinforcement.

### Method

**Subjects.** Three experimentally experienced pigeons, maintained at approximately 85% of their free-feeding body weights, served as subjects.

**Apparatus and Procedure.** The apparatus was a standard three-key, Grason-Stadler pigeon station, Model E6446C, enclosed in a Grason-Stadler, Model E3125A-300, sound-attenuating chamber. The houselight illuminated the chamber throughout the session, and a fan masked noises from outside the chamber. Electromechanical equipment located in another room scheduled the experimental events.

All subjects had previously pecked keys for food reinforcers. Therefore, they were placed directly on several series of multiple schedules in which a baseline multiple schedule was followed by a schedule in which contrast should occur and then baseline was recovered. Table 2 lists the schedules in the random order in which they were presented. It also gives the number of reinforcers presented per session. This number was varied from schedule to schedule to keep sessions from becoming too long.

The components of the multiple schedule alternated every 60 sec. They were signaled by red and white lights that appeared on the center response key. The white light signaled the component of the

multiple schedule listed first: the red light signaled the component listed second. Pecks on the illuminated center key produced a brief feedback click and reinforcers when they were scheduled. The other keys were not illuminated, and pecks on them were ineffective. Reinforcers were scheduled by a series constructed according to the procedure given in Catania and Reynolds (1968, Appendix 2). All other procedural details were the same as those used in Experiment 1. An average of 41 sessions were conducted for each schedule.

### Results and Discussion

Table 3 presents the mean rates of responding emitted during each component of each multiple schedule, calculated over the last five sessions for which each schedule was available. The rates were calculated as they were for Table 1.

Table 3 shows that positive contrast occurred consistently. That is, rates of responding in the constant component increased with decreases in the rate of reinforcement in the variable component and then decreased again with the reintroduction of baseline, with only one exception (Subject 13, VI 30-sec baseline). Table 3 also shows that the subjects discriminated between the components of the multiple schedule during the contrast phase. That is, the rate of responding was always higher during the component that provided the higher rate of reinforcement during that phase. However, Table 3 also shows that the rate of responding in the variable component did not always decrease from the baseline to the contrast phase with decreases in its own rate of reinforcement.

The explanation for this problem is not known. However, the present experiment did not employ as strong a contrast manipulation as that used in other studies. The variable component is usually changed to extinction when positive contrast is studied. The present study only halved the rate of reinforcement. This weaker manipulation was used so that positive and negative contrast could be studied over a wide range of baseline rates of reinforcement by using similar manipulations (i.e., halving or doubling the rate of reinforcement). Had a larger manipulation been used (e.g., delivering  $1/10$  or 10 times the rate of rein-

**Table 3**  
**Rates of Responding in Pecks per Minute in Each Component of Each Multiple Schedule in Experiment 2**

Schedule	Subject 11		Subject 12		Subject 13		Mean	
	Constant Comp.	Variable Comp.	Constant Comp.	Variable Comp.	Constant Comp.	Variable Comp.	Constant Comp.	Variable Comp.
VI 1 min VI 1 min	69.6	58.7	103.0	90.2	86.0	84.4	86.2	77.8
VI 1 min VI 2 min	77.8	57.5	128.9	100.9	138.9	109.6	115.2	89.3
VI 1 min VI 1 min	64.4	63.5	90.2	94.1	91.5	79.1	82.0	78.9
VI 4 min VI 4 min	74.2	71.6	102.1	97.5	69.8	69.8	82.0	79.6
VI 4 min VI 8 min	88.7	68.3	102.4	65.3	98.8	67.3	96.6	67.0
VI 4 min VI 4 min	84.5	72.0	94.4	85.2	96.3	91.4	91.7	82.9
VI 30 sec VI 30 sec	74.3	69.2	93.5	92.6	70.6	67.9	79.5	76.6
VI 30 sec VI 1 min	102.4	85.1	110.6	94.2	90.8	60.3	101.3	79.9
VI 30 sec VI 30 sec	90.2	88.9	76.9	74.6	104.1	104.9	90.4	89.5
VI 15 sec VI 15 sec	71.9	84.7	66.8	60.8	59.3	82.9	66.0	76.1
VI 15 sec VI 30 sec	129.3	87.0	123.1	100.1	117.9	113.1	123.4	100.1
VI 15 sec VI 15 sec	91.5	97.1	96.5	101.0	33.1	30.7	73.7	76.3

Note—Comp. = component.

forcement during baseline), neither positive nor negative contrast could have been studied over a wide range of baseline rates of reinforcement. However, this weaker contrast manipulation may not have been large enough to overcome any fluctuations in response rates that might have occurred over the 41 sessions per schedule that were conducted, on average, in this experiment. Fluctuations in response rates are common for multiple schedules. For example, 2 of the 8 subjects in Spealman and Gollub (1974), with which this study will be compared below, approximately doubled their response rates from one schedule to its recovery.

The present experiment, which conducted a baseline schedule both before and after the contrast manipulation, was designed to minimize the problems that fluctuating response rates create for the measurement of contrast. Contrast was measured only relative to both baseline rates. Figure 3 shows that this control produced reasonably orderly results.

Figure 3 presents the size of positive behavioral contrast plotted as a function of the rate of reinforcement scheduled for each component of the baseline multiple schedule (e.g., the VI 15-sec baseline presents 240 reinforcers per hour). The size of contrast was represented by the differences between the rates of responding emitted during the constant, contrast, component in the contrast phase and the average rate of responding emitted during the same component in the surrounding baseline schedules. The rates of responding were taken from Table 3.

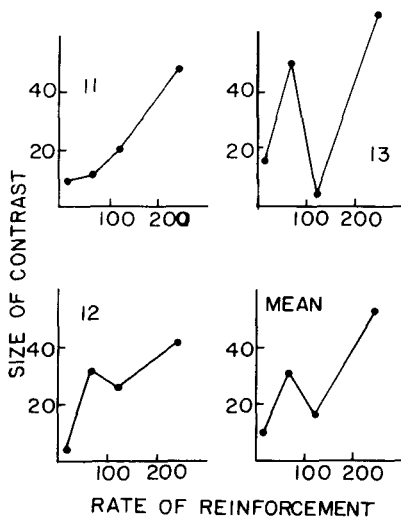


Figure 3. Size of positive contrast (pecks per minute) as a function of the rate of reinforcement (reinforcers per hour) scheduled for each component of the baseline multiple schedules in Experiment 2. Contrast was measured by the difference between the rates of responding emitted during the constant, contrast, component in the contrast phase and the average rate of responding emitted during the same component during the surrounding baseline schedules. Each set of axes represents the results for an individual subject or for the mean of all subjects.

Figure 3 shows that contrast generally increased with increases in baseline rates of reinforcement. The only substantial contradiction to this conclusion is provided by the small size of positive contrast observed for Bird 13 when the VI 30-sec baseline (120 reinforcers per hour) was used. However, Table 3 shows that this was also the one case in which positive contrast was not reliably observed. The rate of responding for this subject during the constant component of the first MULT VI 30-sec VI 30-sec schedule was 70.6/min. This baseline response rate rose to 104.1 responses/min during the second MULT VI 30-sec schedule, a rate higher than that shown during the contrast condition (90.8 responses/min). Thus, for unknown reasons, positive contrast did not actually occur for this subject at this point.

The size of positive contrast changed significantly with changes in the baseline rate of reinforcement [ $F(3,6) = 5.46, p < .05$ ]. The size of contrast for the schedules that delivered 15 reinforcers per hour was shown by *t* test for matched pairs to be significantly different ( $p < .05$ ) from that for the schedules that delivered 240 reinforcers per hour [ $t(2) = 9.50$ ]. The following comparisons were also marginally significantly different ( $.05 < p < .10$ ): 60 versus 240 [ $t(2) = 2.54$ ], 120 versus 240 [ $t(2) = 2.50$ ], and 60 versus 15 [ $t(2) = 2.10$ ] reinforcers per hour.

The results presented in Figure 3 differ from those of past studies which found smaller positive keypeck contrast at higher rates of reinforcement. However, several procedural differences may explain the differences. Reynolds (1963) and Spealman and Gollub (1974) employed multiple schedules with 3-min components instead of the present 1-min durations. Neither changed the rates of reinforcement by a constant ratio to produce contrast. Also, Reynolds conducted fewer sessions per schedule (mean = 18) than did the present study and did not recover baseline after every contrast manipulation.

However, the most likely explanation for the difference in results is that the present study varied the baseline rate of reinforcement over a wider range than did either of the other studies. Reynolds studied responding using 20 and 38 reinforcers per hour as the two baselines. Spealman and Gollub studied responding using 20 and 120 reinforcers per hour as the baselines. Figure 3 indicates that the results of the present study would be less clear if a baseline rate of 240 reinforcers per hour had not been studied. Up to this very high baseline, the results show the variability that is also apparent in Reynolds's and Spealman and Gollub's data.

The present results may question one possible difference between positive contrast for keypecking and treadle pressing. As argued earlier, the size of keypeck contrast has generally decreased with increases in baseline rates of reinforcement (Reynolds, 1963; Spealman & Gollub, 1974). The size of treadle-press contrast may increase with increases in baseline rate of reinforcement (e.g., McSweeney, 1983). The present results question this potential difference between keypecking and treadle press-

**Table 4**  
**The Schedules Conducted in Experiment 3, and the Number of Reinforcers Delivered per Session, in Order of Presentation**

Schedule	Number of Reinforcers
VI 1 min VI 1 min	40
VI 1 min VI 30 sec	40
VI 1 min VI 1 min	40
VI 30 sec VI 30 sec	60
VI 30 sec VI 15 sec	60
VI 30 sec VI 30 sec	60
VI 2 min VI 2 min	20
VI 2 min VI 1 min	25
VI 2 min VI 2 min	20
VI 8 min VI 8 min	5
VI 8 min VI 4 min	8
VI 8 min VI 8 min	5
VI 4 min VI 4 min	10
VI 4 min VI 2 min	15
VI 4 min VI 4 min	10

ing by showing that keypeck contrast increases with increases in baseline rates of reinforcement. Final conclusions, however, should be reserved until a single study examines the form of the function for treadle pressing.

**EXPERIMENT 3**

Experiment 2 showed that positive keypeck contrast generally increased with increases in the baseline rates of reinforcement. Experiment 3 asked whether negative contrast changes according to a similar function.

**Method**

**Subjects.** Four experimentally experienced pigeons, maintained at approximately 85% of their free-feeding body weights, served as subjects.

**Apparatus and Procedure.** The apparatus was the one used in Experiment 2. The procedure was also identical to that used in Experiment 2 except that the subjects responded on the schedules presented in Table 4. The table presents the schedules in the random order in which they were conducted and lists the number of reinforcers delivered per session. An average of 40 sessions were conducted per schedule.

**Results and Discussion**

Table 5 presents the mean rates of responding emitted during each component of each multiple schedule, calculated over the last five sessions for which that schedule was available. The rates were calculated as they were for Table 1.

Table 5 shows that subjects discriminated between the components of the multiple schedule during the contrast phase. That is, rates of responding were higher during the component that provided the higher rates of reinforcement. However, as in Table 3, rates of responding during the variable component did not always increase with increases in their rates of reinforcement from the baseline to the contrast phase.

Again, the relatively small manipulation used to produce negative contrast (i.e., a doubling of the rate of reinforcement) may have been responsible for this problem. This small manipulation may not have been large enough to overcome any fluctuations in response rates that occurred over the 40 sessions conducted per schedule. However, to minimize the problems that fluctuating response rates create for the measurement of contrast, baseline schedules were conducted before and after each contrast phase.

Figure 4 presents the size of negative behavioral contrast plotted as a function of the rate of reinforcement scheduled for each component of the baseline multiple schedule. Again, the size of contrast was measured by using the difference between the rates of responding emitted during the constant, contrast, component in the con-

**Table 5**  
**Rates of Responding in Pecks per Minute in Each Component of Each Multiple Schedule in Experiment 3**

Schedule	Subject 1		Subject 2		Subject 3		Subject 4		Mean	
	Constant Comp.	Variable Comp.	Constant Comp.	Variable Comp.	Constant Comp.	Variable Comp.	Constant Comp.	Variable Comp.	Constant Comp.	Variable Comp.
VI 1 min VI 1 min	18.0	21.7	48.6	41.3	51.9	51.9	79.1	88.0	49.4	50.7
VI 1 min VI 30 sec	15.6	33.4	35.5	49.3	54.2	64.9	52.6	80.3	39.5	57.0
VI 1 min VI 1 min	29.7	28.9	63.0	57.0	51.9	50.5	69.1	76.1	53.4	53.1
VI 30 sec VI 30 sec	36.8	31.9	83.0	69.4	84.6	83.7	101.8	99.1	76.6	71.0
VI 30 sec VI 15 sec	24.9	33.6	71.3	70.3	79.8	100.4	99.0	126.2	68.8	82.6
VI 30 sec VI 30 sec	30.1	30.4	84.4	73.2	103.9	99.4	107.9	115.5	81.6	79.6
VI 2 min VI 2 min	29.0	30.3	76.8	80.3	64.0	63.1	83.0	85.4	63.2	64.8
VI 2 min VI 1 min	19.2	29.3	63.6	92.6	81.1	83.0	71.0	81.9	58.7	71.7
VI 2 min VI 2 min	14.9	20.1	84.5	87.0	66.3	63.5	76.4	91.1	60.5	65.4
VI 8 min VI 8 min	22.8	30.2	64.4	62.4	44.5	40.2	68.3	72.1	50.0	51.2
VI 8 min VI 4 min	19.3	37.2	64.3	78.2	63.0	90.8	50.4	80.4	49.2	71.7
VI 8 min VI 8 min	23.8	27.9	68.2	58.2	72.6	80.3	62.6	62.7	56.8	57.3
VI 4 min VI 4 min	32.2	31.9	64.4	77.2	77.3	59.3	58.5	77.7	58.1	61.5
VI 4 min VI 2 min	23.5	35.2	48.2	74.4	63.7	72.1	59.2	94.6	48.7	69.1
VI 4 min VI 4 min	21.8	24.3	48.6	60.7	75.4	68.8	58.0	64.5	51.0	54.6

Note—Comp. = component.



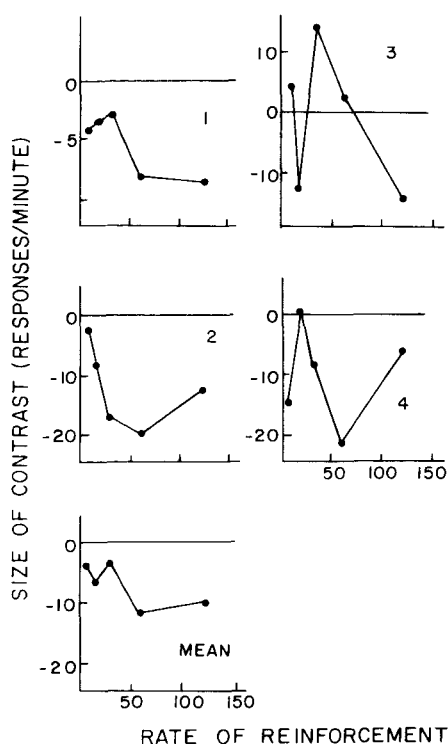


Figure 4. Size of negative contrast (pecks per minute) as a function of the rate of reinforcement (reinforcers per hour) scheduled for each component of the baseline multiple schedules in Experiment 3. Contrast was measured by the difference between the rates of responding emitted during the constant, contrast, component in the contrast phase and the average rates of responding emitted during the same component during the surrounding baseline schedules. Each set of axes represents the results for an individual subject or for the mean of all subjects.

trast phase and the average rates of responding emitted during the same component in the surrounding baseline schedules. The response rates were taken from Table 5. Negative numbers indicate negative contrast. Positive numbers indicate positive induction, defined as an increase in the rate of responding emitted during one component with increases in the rate of reinforcement obtained from the other component.

Figure 4 shows that generally negative contrast occurred. The only failures to obtain negative contrast occurred for Subject 3. Figure 4 also shows that the size of negative behavioral contrast generally increased with increases in the baseline rate of reinforcement. The comparisons for the 15 versus 120 reinforcer-per-hour conditions [ $t(3) = 4.37$ ] and for the 30 versus 60 reinforcer-per-hour conditions [ $t(3) = 3.35$ ] were statistically significantly different ( $p < .05$ ) by  $t$  tests for matched pairs. The points for the 7.5 versus 60 reinforcer-per-hour condition were also marginally significantly different [ $t(3) = 2.15$ ,  $.05 < p < .10$ ].

The less orderly results for negative (Figure 4) than for positive (Figure 3) contrast may have resulted from the

restricted range over which the baseline rates of reinforcement varied for negative contrast. Baseline rates varied from 15 to 240 reinforcers per hour for positive contrast, but from 7.5 to 120 reinforcers per hour for negative contrast. This difference occurred because the rates of reinforcement were changed by a constant ratio from the baseline to the contrast phase for both positive and negative contrast. Baseline rates were halved to produce positive contrast and doubled to produce negative contrast. Baseline rates of reinforcement as large as 240 reinforcers per hour could not be accurately doubled using the present electromechanical equipment. Therefore, negative contrast could not be studied at the high baseline rates of reinforcement used for positive contrast.

Examination of Figure 3 supports this explanation for the difference between positive and negative contrast. The results for positive contrast would have been less orderly if baseline rates of reinforcement had been studied only up to 120 reinforcers per hour. Therefore, the less orderly results for negative than for positive contrast may have resulted from trying to equate the procedures used to produce the two types of contrast.

The results of Experiments 2 and 3 may question competition theory, which predicts that the size of contrast should be greatest for intermediate rates of reinforcement. The largest contrast occurred at the highest rates of reinforcement for all subjects in Experiment 2 and for 2 of 4 subjects in Experiment 3. Competition theorists might argue that their predictions would be confirmed if still higher rates of reinforcement had been studied. The size of contrast might decrease again at extremely high rates. But, then, these theorists must specify the range of rates of reinforcement over which their predictions hold.

The results of Experiments 2 and 3 are generally consistent with Herrnstein's theory. The size of contrast generally increased with increases in the baseline rates of reinforcement. However, the larger size of positive (Experiment 2) than of negative (Experiment 3) contrast is not compatible with Herrnstein's theory for reasonable values of the  $k$ ,  $m$ , and  $R_0$  parameters which are constant across the schedules. For example, if the value of  $k$  is assumed to be 100, the value of  $R_0$  is 10, and the value of  $m$  is 0.50, then the size of positive contrast, as it is measured here, should change from 13.9 responses/min for the VI 4-min baseline to 31.1 responses/min for the VI 15-sec baseline. The size of negative contrast should change from 7.6 responses/min for the VI 8-min baseline to 29.2 responses/min for the VI 30-sec baseline. Thus, the theory predicts that the size of positive and negative contrast will be similar and will change by approximately similar amounts (17.2 responses/min for positive contrast and 21.6 responses/min for negative contrast) over the course of this experiment. This was not the case. Positive contrast was larger and changed by a larger amount. Therefore, the present results join those of other studies (see Williams, 1983, for a review) in questioning the details of Herrnstein's theory.

## GENERAL DISCUSSION

The major finding of the present study is that positive and negative contrast changed as symmetrical functions of two independent variables. Both positive and negative contrast generally increased with increases in component duration for treadle pressing (Experiment 1 and McSweeney, 1982). Both positive and negative contrast generally increased with increases in baseline rates of reinforcement for keypecking (Experiments 2 and 3). This functional similarity suggests that positive and negative contrast are products of the same variables, and will eventually be described by the same theory.

As discussed earlier, the present results also support several specific conclusions about particular theories. The results of Experiment 1 contradict Ettinger and Staddon's (1982) theory, which predicts an inverse relationship between the size of contrast and component duration. Experiment 1 found a direct relationship between positive treadle-press contrast and component duration. Experiments 2 and 3 may contradict competition theory (Hinson & Staddon, 1978), which predicts that contrast should be largest for intermediate rates of reinforcement. Experiments 2 and 3 usually found contrast to be largest at the highest rates of reinforcement. Finally, Experiments 2 and 3 contradict Herrnstein's (1970) theory, which predicts that the sizes of positive and negative contrast should be similar for the present study when reasonable and constant values of the parameters are assumed. Experiments 2 and 3 found that positive contrast was larger than negative contrast.

The results of Experiment 1 may also suggest, but do not compel, the conclusion that contrast differs in important ways for different responses. The absolute sizes of contrast generally varied inversely with component duration for treadle pressing. This functional difference suggests that the responses differ in important ways because the difference helps to rule out some of the simpler hypotheses that have been used to explain the differences between the responses.

First, it has been argued that keypecking and treadle pressing are not fundamentally different, but that changes in low response rates are harder to detect than changes in high response rates (e.g., Davison & Ferguson, 1978). According to this argument, contrast should be harder to detect for treadle pressing than for keypecking because treadle pressing occurs at a lower rate than keypecking.

Second, it has been argued that contrast is difficult to demonstrate for treadle pressing because treadle pressing is relatively insensitive to reinforcement (e.g., Staddon, 1982). Responses that are insensitive to reinforcement change less with a given change in reinforcement than do responses that are sensitive to reinforcement (e.g., keypecking). Therefore, contrast should be harder to detect for treadle pressing.

Third, it has been argued that keypecking and treadle pressing differ only in the degree to which subjects discriminate the components of the multiple schedule. According to this argument, the rates of responding emitted

during the components of a multiple schedule should change in the same direction, not in the opposite direction as required for contrast, if the subjects cannot tell the components apart (Rachlin, 1973). Discrimination should be poorer for treadle pressing than for keypecking because the discriminative stimuli appear directly on the response operandum for keypecking, but not for treadle pressing. Therefore, it should be more difficult to demonstrate contrast for treadle pressing than for keypecking.

These explanations for the difference between keypecking and treadle pressing have been difficult to test, for various reasons. However, the results of Experiment 1 question all of them. All of these hypotheses explain why treadle-press contrast fails to occur under circumstances that produce keypeck contrast, but none of them explain why contrast should change as different functions of component duration for the two responses. Either the hypotheses must be elaborated or other arguments must be invoked to explain the present functional differences.

In the absence of more precise information about the form of these functions, it would be premature to formulate a theory to describe the present results. However, the present results do indicate that the appropriate theory will eventually describe positive and negative contrast similarly. It will also predict that the size of contrast will change with changes in component duration and baseline rates of reinforcement. Finally, if the results of Experiment 1 are confirmed in an experiment that examines keypecking by using a procedure identical to that used for treadle pressing, then the theory must also predict that the functions for keypecking are different from those for treadle pressing.

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