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Contrast effects in response rate and accuracy of delayed matching to sample

John A. Nevin, Timothy A. Shahan, and Amy L. Odum

University of New Hampshire, Durham, NH, USA, and Utah State University, Logan, UT, USA

Abstract

Behavioural contrast is an inverse relation between the response rate in one component of a multiple schedule and the reinforcer rate in an alternated component. To explore possible contrast effects in accuracy as well as response rate, four pigeons were trained in multiple schedules where key pecking produced delayed matching-to-sample trials on a variable-interval schedule. Reinforcer probability for correct matches was constant at .3 in one component, and the conditions of reinforcement were varied in the second component. In Experiment 1, the varied component arranged the same contingencies as the constant component but with reinforcer probabilities of .9 or .1 across conditions. In the varied component, both response rate and accuracy of delayed matching were directly related to reinforcer probability; in the constant component, however, contrast effects on response rate were weak, and there was no evidence of contrast in accuracy of matching. In Experiment 2, the varied component was either variable interval with immediate food reinforcement or extinction. Reliable contrast effects were obtained in both response rate and in accuracy of matching in the constant component, and their magnitudes were correlated within and between subjects. The results of Experiment 2 join previous findings of covariation in the effects of reinforcement on free-operant responding and accuracy of discrimination.

Short-term remembering in nonhuman animals has been studied extensively in the delayed matching-to-sample (DMTS) paradigm. A standard example employs pigeons as subjects with blue or yellow sample stimuli presented on a centre key. After centre-key offset and a retention interval, blue and yellow comparisons are presented on the side keys, and reinforcement is available for responses to the comparison that matches the colour of the sample. The basic dependent variable is the relation between accuracy and retention-interval length known as the forgetting function.

Accuracy in the DMTS paradigm depends on the conditions of reinforcement for correct matches. For example, the level of the forgetting function depends directly on reinforcer probability or magnitude when it is signalled within trials (Brown & White, 2005a; Jones, White, & Alsop, 1995; McCarthy & Voss, 1995; Nevin & Grosch, 1990). It also depends directly on the probability of reinforcement arranged in multiple-schedule components (Odum, Shahan, & Nevin, 2005). In the study by Odum et al., which forms the basis for the research reported here, pigeons produced DMTS trials according to a variable-interval (VI) schedule by pecking the centre key of a three-key array, where the centre-key colour signalled a high (.9) or low (.1) probability of reinforcement for correct matches for a series of trials (we refer to this as the multiple VI DMTS paradigm). Odum et al. found that both VI response rates and DMTS forgetting functions were higher and more resistant to change in the high-probability than in the low-probability component. Previous research by Nevin,

Milo, Odum, and Shahan (2003) drew similar conclusions for multiple VI matching to sample (MTS; i.e., with 0-s retention intervals).

A reliable finding with free-operant multiple VI schedules is that in the steady state, response rate in a constant component depends inversely on the reinforcer rate in an alternated, varied component (e.g., Nevin, 1968; for review see Williams, 1983). The result is termed “behavioural contrast”. In view of our previous work showing similar effects of reinforcer probability on accuracy and on response rate, we ask here whether steady-state behavioural contrast occurs for DMTS accuracy as well as for response rate in the multiple VI DMTS paradigm. Evidence of contrast in both aspects of performance would strengthen the generalization that free-operant responding and accuracy of discrimination are similarly dependent on reinforcement.

A second reason for this study is that contrast in the accuracy of conditional-discrimination performance is specifically predicted by a quantitative model of attending (Nevin, Davison, Odum, & Shahan, in press; Nevin, Davison, & Shahan, 2005, p. 300). The present experiments are not designed to test quantitative aspects of the model but simply ask whether the ordinal prediction of contrast is confirmed.

EXPERIMENT 1

To evaluate the possibility of contrast in DMTS performance, pigeons were trained on two-component multiple VI DMTS with a constant reinforcer probability (.3) for correct matches in one component. The reinforcer probability in the varied component was either higher (.9) or lower (.1) across successive conditions. Our previous work (Odum et al., 2005) led us to expect that both VI response rates and DMTS accuracy in the varied component would be directly related to reinforcer probability. If both VI response rates and DMTS accuracy in the constant component were inversely related to reinforcer probability in the varied component, the results would demonstrate contrast in both aspects of performance.

Method

Subjects—Four White Carneau pigeons served as subjects. All four had served in the study reported by Odum et al. (2005). The pigeons were maintained at 80% (± 15 g) of free-feeding weights by postsession feeding of pelleted pigeon chow as necessary. Between sessions, pigeons were individually housed in a temperature-controlled colony with free access to water under 12:12-hr light/dark cycle.

Apparatus—Four Lehigh Valley Electronics pigeon chambers constructed of painted metal with aluminium front panels were used. The chambers were 35 cm long, 35 cm high, and 30 cm wide. Each front panel had three translucent plastic keys that could be lit from behind with green, red, blue, or yellow light and required a force of about 0.10 N to record a response. Keys were 2.5 cm in diameter and 24 cm from the floor. A lamp (28 V, 1.1 W) mounted 4.5 cm above the centre key served as a houselight. A rectangular opening 10 cm above the chamber floor provided access through a 5-cm by 5.5-cm aperture to a solenoid-operated hopper filled with pelleted pigeon chow. During hopper presentations, the opening was lit with white light, and the houselight and keylights were extinguished. White noise and chamber ventilation fans masked extraneous noise. Contingencies were programmed and data collected by a microcomputer located in an adjacent room using Med Associates® interfacing and software.

Procedure—The procedure was similar to that used by Odum et al. (2005). In view of the pigeons’ previous experience, no pretraining was required. Two components of a multiple schedule, signalled by the colour of the centre key (either red or green), alternated. Pecks to

the lighted centre key changed it to yellow or blue (the sample) on a VI 20-s schedule. The VI schedule was composed of 20 intervals generated according to the method described by Fleshler and Hoffman (1962). Separate lists of intervals were maintained for the two multiple-schedule components. The sample remained on until the first peck after 3 s or a total of 6 s had elapsed. After sample offset, the centre key returned to the colour present during the VI for a 0.1-, 2-, 4-, or 8-s retention interval.

Following the retention interval, the centre key was extinguished, and the side keys were lighted, one yellow and one blue (the comparisons). The key that was lighted with each colour varied randomly across trials, with each sample colour (blue or yellow) appearing an equal number of times at each retention interval over the course of the session. A single peck turned off the side keys and was followed by food or blackout. Components differed in the probability that choice of the comparison colour that matched the sample colour would produce food. In the constant component, correct matches had a probability of .3 of producing 2-s access to food. Nonreinforced matches and incorrect choices produced a 2-s blackout. In the varied component, correct matches had a probability of .9 or .1 of producing 2-s access to food across successive conditions. For all birds, the order of conditions was .9, .1, .9, .1, with 20 sessions of exposure to each condition. As in the constant component, non-reinforced matches and incorrect choices produced a 2-s blackout. The constant component was signalled by red for subjects P51 and P97 and by green for P74 and P85, with colour assignments reversed for the alternated component. The component that began the session was chosen randomly. Components alternated after blocks of four trials that contained one presentation of each retention-interval duration. The order of durations was chosen randomly within each block. Components were separated by a 15-s inter-component interval (ICI) during which the houselight was on, and the keys were dark. Experimental sessions were conducted daily at approximately the same time and ended after completion of 12 components of each type. Data from the last 10 sessions of each condition were used in all analyses.

Measures: To assess performance during the VI portion of the schedule, response rates on the centre key were calculated separately for the varied and constant components. Time and pecks during DMTS trials were excluded from VI response rates. To assess performance during the DMTS portion of the schedule, choices of the blue or yellow comparison given a blue or yellow sample were recorded separately for each retention interval for each component. These values were used to calculate $\log d$, a measure of conditional discrimination performance (see Davison & Tustin, 1978). This measure is calculated as:

$$\log d = 0.5 \log \left[\frac{(B_y | S_y / B_b | S_y)(B_b | S_b / B_y | S_b)}{1} \right] \quad 1$$

in which B_y is the number of choices of the yellow comparison, and B_b is the number of choices of the blue comparison, each totalled separately for trials on which a yellow sample (S_y) or blue sample (S_b) was presented. $\log d$ is the logarithm of the geometric mean of the ratios of correct to incorrect choices and has several desirable properties. Unlike percentage correct, $\log d$ is independent of bias for one comparison stimulus over another and has a range of 0 (no discrimination) to infinity (all choices correct on an indefinitely large number of trials). When the number of trials is limited to a practicable value, it is often the case that one or more of the numbers on the right of Equation 1 is zero, and it is therefore common to add a small number (here we used 0.25, as recommended by Brown & White, 2005b) to each term to allow calculation of $\log d$ (see Alsop, 2004, for discussion). With this correction, for 12 trials per retention interval per component in each session, pooled over 10 sessions, the maximum value of $\log d$ is 2.38 at each retention interval.

Statistical evaluation: As shown below, forgetting functions were found to be essentially parallel, so the separation between them was expressed as the difference in $\log d$ values between the .9 and .1 conditions averaged across retention intervals. Because replication within subjects across successive pairs of conditions is as important as replication between subjects in small-N research, the reliability of the average difference in $\log d$ was evaluated by paired t tests with two comparisons per subject for each of 4 subjects, making eight comparisons in all. The reliability of differences in response rate was evaluated in the same way.

Results

The stability of VI response rates was assessed by comparing performance in Sessions 11–15 and 16–20. Average response rates differed by less than 5% between 5-session blocks, suggesting reasonable stability during the final 10 sessions of each condition. Figure 1 summarizes the results averaged across subjects and replications. Varied-component response rates were higher in the .9 condition than in the .1 condition in 7 of 8 comparisons; the difference across subjects and replications was statistically significant, $t(7) = 3.91$, $p = .004$. Constant-component response rates were lower in the .9 condition than in the .1 condition in 3 of the 4 subjects (6 of 8 comparisons) but the difference fell short of significance across subjects and replications, $t(7) = 2.15$, $p = .07$.

Figure 2 presents the forgetting functions in the varied and constant components, averaged across subjects and replications. The left panel shows that forgetting functions in the varied component were higher in the .9 condition than in the .1 condition, with no consistent difference in the separation between them across retention intervals. Because the forgetting functions were essentially parallel, differences in overall accuracy could be expressed as differences in the values of $\log d$ averaged across retention intervals. Overall accuracy was higher in the .9 condition than in the .1 condition in 8 of 8 comparisons, and the difference was significant across subjects and replications, $t(7) = 5.33$, $p = .001$. The right panel shows that average forgetting functions in the constant component overlapped, and in the individual data, overall accuracy was consistently lower in the .9 condition than in the .1 condition for only 1 of the 4 subjects. Thus, there was no evidence of contrast in the forgetting functions.

Because the VI DMTS paradigm provides simultaneous measurement of VI response rate and DMTS accuracy, it is of interest to examine the data for covariation in those aspects of performance. Figure 3 presents the covariation between contrast effects on overall accuracy and response rate as a scattergram, with pairs of data points for within-subject replications connected by lines. The magnitudes of the effects were calculated as ratios of the values with reinforcer probability .1 in the alternated component to corresponding values with reinforcer probability .9 in the alternated component—that is, $(\log d_{.1})/(\log d_{.9})$ and $(\text{resp}/\text{min}_{.1})/(\text{resp}/\text{min}_{.9})$, where values greater than 1.0 represent contrast. Only P85 exhibits a positive relation between these measures; for the other three birds, the relation is negative. Thus, even though P97 and P51 exhibited small contrast effects in VI response rates, they gave no evidence of contrast in DMTS accuracy.

Discussion

The effects on response rates and forgetting functions of reinforcer probability in the varied component, which was either .9 or .1 in successive conditions, replicated the findings of Odum et al. (2005) who arranged reinforcer probabilities of .9 and .1 in multiple VI DMTS

¹Complete tables of individual data are available from the first author.

components within sessions. Therefore, the effect of reinforcer probability on DMTS accuracy is robust.

The failure to obtain large and reliable contrast effects in response rate may be attributable to the 15-s ICI separating multiple-schedule components. For example, Nevin, Mandell, and Atak (1983) observed response-rate contrast in only 1 of 6 birds with a 30-s ICI, whereas Nevin (1992) observed substantial contrast in 5 of 5 birds with a 2-s ICI. Accordingly, replication with a brief or zero ICI might be more likely to yield response-rate contrast in the constant component.

Furthermore, evaluation of contrast effects (or their absence) in constant-component forgetting functions may be complicated by the fact that sample and comparison stimuli were the same in both components. Thus, the effects of more or less frequent reinforcement in the alternated component might generalize to the constant component, masking potential evidence of contrast. To exclude this possibility, DMTS trials might use different colours or be omitted altogether in the alternated component.

EXPERIMENT 2

Because contrast effects were weak or absent in Experiment 1, we replicated Experiment 1 with no ICI and with DMTS trials omitted from the alternated component, and we conducted more sessions per condition.

Method

Subjects—The subjects in Experiment 1 were continued under the same deprivation conditions.

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

Procedure—The procedure of Experiment 1 was modified by omitting the ICI and by removing DMTS trials from the varied component. Instead, the varied component lasted for a fixed duration of 60 s rather than until completion of four DMTS trials, and centre-key pecks were either reinforced with food according to a VI 25-s schedule or subjected to extinction (EXT) across successive conditions. The VI 25-s schedule yielded a slightly higher reinforcer rate than the VI DMTS component with a reinforcer probability of .9 in Experiment 1; extinction, of course, yielded fewer reinforcers than the VI DMTS component with a reinforcer probability of .1. Consequently, the between-condition difference in varied-component reinforcer rates was somewhat larger than that in Experiment 1. Sessions always started with the varied component of VI or Ext, whichever was in effect for that subject and condition. The constant component was VI DMTS with reinforcer probability .3, as in Experiment 1, and all other aspects of the procedure, such as number of components per session and reinforcer duration, also remained the same. Across subjects, the varied schedule was either VI or Ext for 30 consecutive sessions and then switched to Ext or VI for the next 30 sessions. Both conditions were replicated over two additional 30-session blocks. The order of conditions was counterbalanced across birds: VI Ext VI Ext for Birds 85 and 97, and Ext VI Ext VI for Birds 51 and 74. Data from the last 10 sessions of each condition were used in all analyses, and statistical significance was evaluated as in Experiment 1.

Results

Across birds and conditions, average constant-component response rates differed by less than 1% between Sessions 21–25 and 26–30, so the data of the last 10 sessions represent stable performance. Figure 4 presents the VI response rates in the varied and constant

components for the final 10 sessions, averaged across birds and replications with VI or Ext in the alternated component. In the varied component, the difference in response rates in the two conditions was large and highly significant by inspection. In the constant component, response rate was higher when the alternated component was Ext than when it was VI for only 3 of the 4 birds in both replications, but was statistically significant because of the magnitudes of the differences, $t(7) = 2.35, p = .026$.

Figure 5 presents the constant-component forgetting functions averaged across birds and replications with VI or Ext in the alternated component. The function for Ext is consistently above that for VI, suggesting contrast in DMTS accuracy, but the absolute difference is small. Nevertheless, the difference in overall accuracy was statistically significant across birds and replications, $t(7) = 2.69, p = .016$.

Figure 6 presents the covariation between contrast effects in overall accuracy and response rate as a scattergram similar to Figure 3. The magnitudes of the effects were calculated as ratios of the values with extinction in the alternated component to corresponding values with VI in the alternated component—that is, $(\log d_{\text{Ext}})/(\log d_{\text{VI}})$ and $(\text{resp}/\text{min}_{\text{Ext}})/(\text{resp}/\text{min}_{\text{VI}})$. The figure shows that subjects with larger contrast effects on response rate also exhibited larger contrast effects on overall accuracy. Correlations were also evident within subjects between replications: Higher accuracy ratios were associated with higher response-rate ratios for each bird, as indicated by the ordering of data points within each pair. Thus, although there was substantial individual variation in the effects of alternated-component reinforcement on constant-component response rate and accuracy, there was a high degree of consistency in the relation between those measures.

Discussion

Experiment 2 extended the many demonstrations of steady-state contrast effects on response rate in a constant multiple-schedule component to the VI DMTS paradigm where responding was reinforced by onset of DMTS trials rather than by immediate primary reinforcers. It also demonstrated contrast effects on DMTS accuracy in that the level of the forgetting function in a constant VI DMTS component of a multiple schedule was inversely related to the reinforcer rate in the varied component. As in previous work by Nevin et al. (2003), reinforcer effects on accuracy were correlated, across subjects and conditions, with effects on response rate.

GENERAL DISCUSSION

Two experiments explored steady-state contrast effects on response rates and forgetting functions within the multiple VI DMTS paradigm. In Experiment 1, reinforcer probability for correct matches was .3 in the constant component, with .9 or .1 in the varied component alternating across conditions, where components were separated by a 15-s ICI. In the varied component, both response rates and forgetting function levels were directly related to reinforcer probability, replicating Odum et al. (2005). In the constant component, however, response-rate contrast effects were weak, average forgetting functions did not differ, and there was no consistent relation between differences in response rate and accuracy for individual subjects.

In Experiment 2, there was no ICI, and DMTS trials were omitted and replaced with a VI 25-s schedule of food reinforcement or extinction in the varied component, with training in each condition extended to 30 sessions. As a result of these procedural changes, we obtained larger and more reliable steady-state contrast effects on response rate and on the level of the forgetting function in the constant component, with consistent relations between these measures within and between subjects.

The covariation of response rate and accuracy in Experiment 2 extends the findings of Nevin et al (2003) and Odum et al (2005). Nevin et al. examined both baseline response rates and their resistance to change in multiple VI MTS with 0-s retention intervals and found that both response rates and MTS accuracy were higher and more resistant to change in the component with the higher probability of reinforcement. Odum et al. repeated those results with DMTS retention intervals ranging from 0.1 to 8 s. Thus, there is substantial evidence that reinforcement variables exert functionally similar effects on response rates and DMTS accuracy.

Our finding that steady-state constant-component DMTS accuracy depended inversely on alternated-component reinforcer rate in Experiment 2 is related to previously demonstrated effects of reinforcers that are extraneous to the DMTS task. For example, Wilkie (1984, Exp. 2) trained pigeons on matching of key location with a 1-s retention interval and found that presenting response-independent food during the intertrial interval in test sessions reduced matching accuracy. Wilkie's result was replicated by Blough (1998) in a conditional wavelength discrimination task with no retention interval. Relatedly, Nevin et al. (2003) observed reductions in accuracy when response-independent food was presented for a few sessions during intervals between components in multiple VI MTS, and found that the magnitude of the reduction was inversely related to the probability of reinforcement for correct matches. Most recently, Brown and White (2005c) varied the rate of extraneous reinforcers during retention intervals in DMTS factorially with the probability of reinforcement for correct matches, with each condition in effect for enough sessions to achieve stability. They observed small but systematic decreases in accuracy as retention-interval reinforcer rate increased relative to reinforcers for correct matches when retention-interval reinforcers were contingent on centre-key pecks. However, there was no effect on accuracy when reinforcers were presented independently of responding. Blough (1998) also observed decreases in accuracy when pecks at the sample were occasionally reinforced during test sessions.

The results of Experiment 2 extend these earlier results in several ways. First, the effects were evident in the steady state, unlike the probe-test results of Wilkie (1984), Blough (1998), and Nevin et al. (2003). Second, reinforcers in the alternated component occurred outside the constant-component VI DMTS trials and thus were temporally distant from DMTS trials, unlike the reinforcers arranged by Wilkie, Blough, and Brown and White (2005c).

The foregoing results have been interpreted in various ways. Wilkie (1984) interpreted the effects of intertrial reinforcers as weakening reinforcement expectancy; Blough (1998) interpreted his findings in relation to a memory model; and Brown and White (2005c) interpreted their results as competition with remembering by other behaviour during retention intervals. Nevin et al. (2003) interpreted their results as evidence that the strengthening and disruption of stimulus control were related to reinforcement in the same way as free-operant response rate, and Nevin et al. (2005) subsequently showed that the results of Nevin et al. (2003) followed directly from a quantitative model of the effects of reinforcement on attending.

As noted above, the model of attending proposed by Nevin et al. (2005) for MTS, and extended to DMTS by Nevin et al. (in press), predicts that accuracy in a constant component of multiple VI DMTS must be inversely related to the reinforcer rate in the alternated component. Thus, the results of Experiment 2 support the model, whereas those of Experiment 1 do not. It is not immediately obvious how the model can be adapted to account for that difference in outcomes, or for the various results reported by Wilkie (1984), Blough (1998), and Brown and White (2005c) with different procedures. Future research may

identify those circumstances under which reinforcers that are extraneous to a discrimination task do or do not affect the accuracy of performance and thereby help to identify the mechanisms underlying the effects. The present finding of correlated effects on accuracy and response rate may provide guidance in this endeavour.

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Figure 1.

Average response rates in the varied component with reinforcer probabilities of .9 and .1 (left columns), and in the constant component with reinforcer probability .3 (right columns). Varied-component reinforcer probabilities are indicated by open and shaded bars. Range bars indicate the standard error of the mean.

Figure 2.

Average values of $\log d$ as functions of the retention interval. The left panel presents forgetting functions for the varied component with reinforcer probabilities of .9 and .1, and the right panel presents forgetting functions in the constant component with reinforcer probability .3; varied-component reinforcer probabilities are indicated in the legend. Range bars indicate the standard error of the mean.

Figure 3.

Ratios of overall accuracy in the constant component with reinforcer probability .1 in the alternated component to overall accuracy with reinforcer probability .9 in the alternated component are plotted in relation to corresponding ratios of response rates for individual subjects with lines connecting replications.

Figure 4.

Average response rates in the varied component with VI 25-s or extinction (left columns) and in the constant component with reinforcer probability .3 (right columns). The varied-component schedule is indicated by open and shaded bars. Range bars indicate the standard error of the mean.

Figure 5.

Average values of $\log d$ in the constant component as functions of the retention interval when the varied component was VI 25-s (VI alt) or extinction (Ext alt). Range bars indicate the standard error of the mean.

Figure 6. Ratios of overall accuracy in the constant component with extinction in the alternated component to overall accuracy with VI reinforcement in the alternated component are plotted in relation to corresponding ratios of response rates for individual subjects, with lines connecting replications.