

Discriminative proprieties of Vary and Repeat contingencies

Alessandra da Silva Souza^{a,b,*}, Josele Abreu-Rodrigues^a

^a Universidade de Brasília, Brazil

^b University of Zürich, Switzerland

ARTICLE INFO

Article history:

Received 23 February 2010

Received in revised form 19 June 2010

Accepted 25 June 2010

Keywords:

Contingency discrimination

Matching

Mixed schedule

Pigeons

Repetition

Variation

ABSTRACT

Pigeons were trained on an arbitrary matching-to-sample task in which Vary and Repeat contingencies served as sample stimuli. During the sample component, two keys were lit red and a four-peck sequence was reinforced if its frequency was less than a certain threshold (Vary sample) or if it comprised one of two target sequences (Repeat sample). During the comparison component, two keys were lit white and green, and correct choices depended on the previous sample contingency. Pigeons learned to emit high and low variability levels during the sample, and correct matching choices were obtained. In two discrimination testing phases, the requirement of variation (Vary sample) or of repetition (Repeat sample) was parametrically manipulated such that behavioral variability became undifferentiated between samples (low sample disparity) and then differentiated (high sample disparity) again. Accurate choices fell to chance under low sample disparity conditions, but improved under high disparity conditions. The results provide evidence that high and low variability levels can be produced in the absence of antecedent cues and that pigeons can accurately report whether they had experienced a Vary or a Repeat contingency, thus indicating that those contingencies may serve discriminative functions.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Behavioral variability can be functional. Behaving in varied, unpredictable or innovative ways can be effective in some contexts (e.g., playing a game, creating a piece of artwork, solving a problem); whereas precise, predictable or repetitive responses are more appropriate in some other conditions (e.g., performing a surgical incision, practicing a physical exercise, operating a machine). Accordingly, several studies have demonstrated that when confronted with environmental demands of variation and repetition, humans and non-human animals learn to display high and low levels of behavioral variability, respectively (Machado, 1989; Neuringer, 1986; Page and Neuringer, 1985; Stokes, 1999).

For example, Machado (1989) trained pigeons to emit variable patterns of four pecks across two side keys. Requirements of low, intermediate and high levels of variability for reinforcement, while the global probability of reinforcement was held constant, produced corresponding levels of behavior variation. Such demonstration of sensitivity to reinforcement contingencies led to the conclusion that variability is an operant dimension of behavior (see Neuringer, 2002, 2004 for a review).

Further evidence of the operant nature of variability was obtained in studies in which the effects of discriminative stimuli (S^D) upon variation and repetition were examined (Abreu-Rodrigues et al., 2004, 2005; Cohen et al., 1990; Denney and Neuringer, 1998; Page and Neuringer, 1985; Ward et al., 2008). For example, Page and Neuringer (1985) trained pigeons to emit sequences of pecks across two keys under a multiple Vary–Repeat schedule. In the Vary component, in which the response keys were lit red (S^D), a sequence had to differ from the previous five ones to be reinforced. In the Repeat component, in which the keys were lit blue (S^D), only a specific sequence was reinforced. Each component was in effect until the delivery of the tenth reinforcer. High and low variability levels were observed under the red and blue S^D s, respectively. Switching the S^D s between components reduced the percentage of reinforced sequences under both contingencies, but across sessions those percentages increased, thus demonstrating control by the antecedent stimuli.

Denney and Neuringer (1998) provided a more compelling evidence of discriminative control. These authors suggested that the consequences for varied and repetitive behaviors – i.e., the response–stimuli (R–S) contingency – similarly to what happens with antecedent stimuli, could provide information about the reinforcement schedules in place, and thus serve discriminative functions. To minimize this possibility, they trained rats to emit sequences of four lever presses under a multiple Vary Yoke schedule, whose components alternated after every reinforcer with a 50% probability. In the Vary component, infrequently emitted sequences were required for reinforcement, while in the

* Corresponding author. Present address: Universität Zürich, Psychologisches Institut, Allgemeine Psychologie (Kognition), Binzmühlestrasse 14/22, CH-8050 Zürich, Switzerland. Tel.: +41 44 63 57469; fax: +41 44 63 57479.

E-mail addresses: a.souza@psychologie.uzh.ch, alessandra.psi@gmail.com (A.S. Souza), abreu@unb.br (J. Abreu-Rodrigues).

Yoke component, sequences were reinforced independently of variability, but with the same probability obtained in the Vary component. Accordingly, variability was higher in the Vary than in the Yoke component. Furthermore, increases and decreases in variability were observed right after the presentation of the Vary and Yoke S^D s, respectively, thus indicating discriminative control of sequence variation without the confounding effects engendered by the contact with the reinforcing consequences.

Interestingly, the question of whether R–S contingencies can serve discriminative functions for varied and repetitive behaviors, as suggested by Denney and Neuringer (1998), has not been systematically investigated. This issue seems relevant because adaptive functional variability levels do not depend only upon learning to respond in varied and repetitive ways, but also rely on the discrimination of when to vary and when to repeat. This discrimination has been extensively demonstrated in the presence of antecedent stimuli, but would it occur in conditions in which such stimuli are lacking?

To the best of our knowledge, only one unpublished study attempted to examine this issue. Hopson, Burt, and Neuringer (as cited by Neuringer, 2002) reinforced varied and repetitive sequences across two alternated, non-sigaled conditions – i.e., under a mixed Vary–Repeat schedule. In the Vary component, infrequent sequences were reinforced, whereas in the Repeat component, a specific sequence was reinforced. High and low variability levels were obtained under the Vary and Repeat components, respectively. To test whether the R–S contingencies were functioning as an S^D , the probability of varying over repeating was analyzed just after a non-sigaled switch from one component to the other. If the contingency was functioning as a cue for change, then switches from the Repeat to the Vary component should increase the probability of varying, whereas switches from the Vary to the Repeat component should increase the probability of repeating; however, if the R–S contingency was not an S^D , than both types of switches should increase variability, because switching implied extinguishing the response that was being reinforced, and withholding reinforcement induces variability (e.g., Neuringer et al., 2001). In accordance with the former prediction, switches from the Vary to the Repeat component increased the probability of repeating instead of varying.

Although Hopson et al. (cited by Neuringer, 2002) provided suggestive evidence of discriminative control, one can still argue that the differentiated patterns observed were a result solely of the reinforcing effects of the Vary and Repeat contingencies. Since only one behavioral index was generated in their experiment – namely the probability of varying over repeating – the same behavior that was reinforced by the contingency was taken as an indicator of its discriminative function. Therefore, this procedure does not allow researchers to identify the specific contribution of the discriminative and reinforcing functions of these contingencies. Given this consideration, one purpose of the present study was to disentangle those functions such as two behavioral indexes could be obtained: one revealing discriminative control and another, reinforcement effects. To attain this goal, we used the experimental preparations typically employed in contingency discrimination investigations. Such preparations will be briefly reviewed in what follows.

The discriminative proprieties of reinforcement contingencies have been extensively investigated by using arbitrary matching-to-sample (MTS) tasks. In this arrangement, two contingencies (sample stimuli) are presented under a mixed schedule. In each trial, the requirement of one of the contingencies must be met. Next, two comparison stimuli are presented, and the subject has to choose one comparison over another based on the sample con-

tingency just presented. The MTS task provides two independent behavioral indexes: one refers to the reinforcing effects of contingencies, and it is revealed by the behavioral differentiation observed in the sample performance; the other refers to the discriminative effects of those contingencies, which are considered to account for the pattern of choices obtained in the presence of the comparison stimuli (e.g., Lattal, 1975).

For instance, Lattal (1975) used an arbitrary MTS task to demonstrate that responding according to a differential-reinforcement-of-low-rate (DRL) schedule or a differential-reinforcement-of-other-behavior (DRO) schedule could serve discriminative functions. Pigeons pecked a white centered key according to a DRL or DRO contingency. Following completion of the contingency requirement, two side keys were lit green and red and served as comparison stimuli. Pigeons learned to choose the green key after the DRL-sample and the red key after the DRO-sample with high accuracy. This arrangement allowed researchers to observe differentiated patterns of responding in the DRL and DRO contingencies (i.e., a reinforcing effect), and also the effects of those contingencies upon choices (i.e., their discriminative effect).

A second advantage of the MTS task is that different tests of discriminative control can be performed. For example, one can change the assumed controlling aspect of the sample contingency and observe its effect upon the accuracy of choice. This manipulation is usually assumed to change the disparity between samples by making them more similar. In the study of Hobson (1975), two fixed-ratio (FR) schedules were presented as sample stimuli. During high disparity conditions, two very distinct ratios were presented as samples (e.g., FR 10 vs. FR 30 schedule). In subsequent conditions, the difference between ratios was gradually reduced (e.g., FR 15 vs. FR 30; FR 25 vs. FR 30; FR 29 vs. FR 30), thus producing lower sample disparities. Accuracy of discrimination was a direct function of sample disparity, thus indicating that the discriminated choices were in fact controlled by the number of responses made in the sample contingency.

Given the advantages just described, arbitrary MTS tasks have been used to examine the discriminative proprieties of different aspects of the contingencies in effect during the sample stimuli, such as: number of responses (Hobson, 1975; Pliskoff and Goldiamond, 1966; Rilling and McDiarmid, 1965; Shimp, 1982), presence or absence of responses (Lattal, 1975, 1979; Zentall et al., 2001), response duration (Zirias and Silberberg, 1978), inter-response times (Odum and Ward, 2004; Reynolds, 1966; Shimp, 1981, 1983), response rate (Lionello-DeNolf and Urcuioli, 2003; Okouchi and Songmi, 2004), response location (García and Rodríguez, 2006), reinforcement density (Commons, 1979; Jones and Davison, 1998), interreinforcer interval (Okouchi, 2003), and response–reinforcer dependency (Killeen, 1978).

The points raised above suggest that the MTS task can be an interesting procedure to evaluate the discriminative effects of Vary and Repeat contingencies. Therefore, in the present experiment, pigeons were exposed to a MTS task in which Vary and Repeat contingencies served as sample stimuli, and choice of two comparison stimuli depended on the previous sample contingency. This procedure allowed us to demonstrate high and low variability levels under a non-differential stimuli condition (i.e., the sample performance); and to examine if the Vary and Repeat contingencies could function as an S^D for the subsequent choice of the comparison stimuli. Moreover, in two testing phases, the requirement of variation (Vary sample) or of repetition (Repeat sample) was parametrically manipulated such that behavioral variability became undifferentiated between samples (low sample disparity) and then differentiated (high sample disparity) again. The goal was to demonstrate that the requirements of variation over repetition (but other contingency parameters) were in fact controlling choices.

2. Materials and methods

2.1. Subjects

Three homing pigeons with prior experimental histories served as subjects. Pigeons were maintained at 80% of their free-feeding weight, with free access to water in their home-cages, and under a light–dark circle of 12 h (dark period from 7 pm to 7 am). Pigeons obtained food only in the experimental sessions. In the case the animal was 20 g below his experimental weight, sessions were not conducted and the animal received free food until weight recovery. Two pigeons (A1 and A3) had previous experience with a MTS task in which Vary and Yoked contingencies served as samples for choice responses. Pigeon A2 had experience with a repetition contingency in which a specific four-peck sequence (i.e., LRLR sequence) was reinforced. Just after such experiences, the present experiment began.

2.2. Apparatus

The experimental chamber measured 35 cm long, 28 cm deep, and 28 cm high. The work panel contained four translucent keys, 2.5 cm in diameter, horizontally displayed on the wall, and located 18 cm above the floor. The keys were identified, from left to right, as keys 1, 2, 3, and 4. Keys 1 and 2, and keys 3 and 4 were 3.5 cm apart, while keys 2 and 3 were 7 cm apart. Only keys 2 and 3 were used in this experiment. Key 2 could be lit red or white, and key 3 could be lit red or green. A Gerbrands food magazine delivered mixed grain through a 4 cm by 4 cm opening centered on the work panel, and located 4 cm above the floor. A white houselight was set on the middle of the opposite wall, 19 cm above the floor. The houselight and the keys were darkened and inoperative during grain presentations, and the hopper was illuminated by a white light. All events were controlled by a 486 DX2 40 MHz microcomputer connected to the chamber by a MED–PC interface system.

2.3. Procedure

Sessions were conducted daily, seven days a week at approximately the same time. Due to the subjects' experimental history, no hopper or key-peck training was necessary.

2.3.1. MTS task

The final procedure employed in the present study comprised an arbitrary MTS task. Its general features are illustrated in Fig. 1. At the start of every matching trial, keys 2 (left, L) and 3 (right, R) were lit red, and the subjects were required to emit a sequence of four pecks across these keys. There were 16 different possible sequences (e.g., LRRR, RRLl, LLLL, and so on). A discrete-response procedure was in effect (cf. Page and Neuringer, 1985). According to this procedure, each of the first three key-pecks turned the key-lights off for a 0.5-s period (pecks during this interval reset it). The fourth peck was followed either by 2-s access to mixed grain (i.e., a reinforcer, S^R) or by a 2-s blackout (BO), during which all lights were turned off. The four-peck sequences produced reinforcement or blackouts according to a mixed Vary–Repeat schedule.

In the Vary component (hereafter called Vary sample), any of the 16 possible sequences could produce reinforcers, provided that its weighted relative frequency was less or equal to a threshold value (cf. Denney and Neuringer, 1998). The relative frequency of each sequence was calculated by dividing its number of occurrences by the total number of emitted sequences. The relative frequencies at the start of each session were taken from the end of the preceding session. To weight recent sequences more than past ones, after reinforcer delivery each of the 16 relative frequencies was multiplied by a weighting coefficient ($w = 0.95$), resulting in an exponential

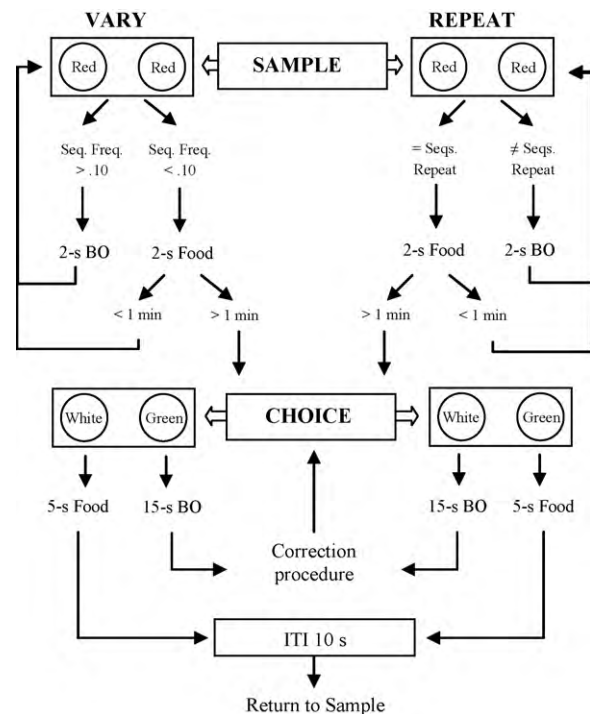


Fig. 1. Diagram of the matching-to-sample (MTS) task.

decrease in the contribution of past sequences. If the weighted relative frequency of the current sequence was less than or equal to the threshold, then it was reinforced; otherwise, a 2-s BO period occurred. The threshold was set at 0.10 in all experimental phases except for the Vary Testing Phase (this point will be explained in detail below). In the Repeat component (hereafter called Repeat sample), only two pre-selected four-peck sequences were eligible to reinforcement. For subject A1, the repeat sequences were LLLL and RRLl; for A2, LRRR and LRLR; and for A3, RLLL and LLRR.

Given that some studies have indicated that long sample durations increase the accuracy of discrimination compared to short sample durations (Hartl et al., 1996; Nelson and Wasserman, 1978; Urciuoli et al., 1999), and that variability is a propriety of a set of events compared to each other, it seemed more adequate to give enough time for the subjects' behavior to contact the Vary and Repeat contingencies. Therefore, a sample contingency remained in effect in each trial until two criteria were satisfied in the following order: first, 60-s had elapsed, and second, a reinforcer had been delivered. The first criterion was employed to guarantee enough exposure to the Vary and Repeat samples, and the second, that at least the last emitted sequence was correct.

Following the sample criteria completion, keys 2 and 3 were lit white and green (comparison stimuli), respectively. A single peck to either comparison key turned both of them off and produced either 5-s access to mixed grain (S^R) or a 15-s BO period, depending on which comparison key has been pecked. White choices in Vary-sample trials and green choices in Repeat-sample trials were reinforced (i.e., correct choices), whereas the opposite choice produced the BO period (i.e., incorrect choices). In sum, in the present study, subjects obtained a smaller amount of reinforcement or punishment (BO) for their performance during the sample-contingencies, and a larger amount of reinforcement or punishment for choosing the correct and incorrect comparisons, respectively (see Lattal, 1979 for a similar procedure).

After an incorrect choice (and its consequence), the comparison stimuli were re-presented until a correct choice occurred – i.e., a correction procedure was in effect. During this procedure, cor-

rect and incorrect choices were followed by the same consequences described above, but those responses were not considered for subsequent data analysis. After the reinforcement of a correct choice, a 10-s intertrial interval (ITI) was implemented, and then a new matching trial was started. Thus, each trial began with the sample stimulus and ended with reinforcement for choosing the correct comparison. Moreover, forced-choice trials were programmed in the beginning of a block of trials to increase accuracy. In these forced trials, only the correct choice comparison was present after a sample stimulus.

2.3.2. Preliminary training

A preliminary training was required before the implementation of the MTS task just described. The duration of the preliminary training was relatively long (for pigeon A1, 99 sessions; for pigeon A2, 235 sessions; and for pigeon A3, 134 sessions). This phase comprised several steps intended to gradually establish the discriminative control by the Vary and Repeat contingencies over matching responses. In the first step, two sequences (hereafter, called the trained repeat sequences) were chosen to be reinforced in the repetition contingency. The trained repeat sequences were selected from a variation (pigeons A1 and A3) or repetition (pigeon A2) baseline of sequences, and were the most frequent ones, except if the most frequent ones were the LLLL and RRRR sequences, in which case the next most frequent sequences were selected. In the second step, subjects were exposed to a modified version of the MTS task in which case only the Repeat sample was presented. In the third step, the MTS task comprised the Vary or the Repeat samples, presented alternately between sessions. In the fourth step, the Vary and Repeat samples were presented within the same session (the first half of the session with one sample and the second half with the other). In the fifth and sixth steps, the Vary and Repeat samples were alternated several times during each session (first, two times, and then several times per session). After the sixth step, the experimental phases with the final MTS task (described above) were implemented. In all steps, subjects performed trials in which only the correct comparison was available (forced-choice) and trials in which both comparisons were available (free-choice) for choice. For more details of the preliminary training, please contact the authors.

The experimental procedure comprised three phases: Baseline, Vary Testing, and Repeat Testing. After each testing phase, subjects were re-exposed to the Baseline Phase. Table 1 presents a summary of the experimental design, stability criterion, and number of sessions in each phase.

2.3.3. Baseline

The Vary and Repeat samples were presented within blocks composed of six matching trials: two forced-choice trials (one with each sample), followed by four free-choice trials (two consecutive trials with each sample). The order of presentation of the Vary and Repeat samples were balanced across trials. Reinforcement, BO, contingency requirements, and the correction procedure were identical to those described in the MTS task.

Accurate matching responses were not obtained for pigeon A2 after 28 sessions of exposure to this procedure. Therefore, a different baseline procedure was implemented for this pigeon. Each block was composed of four forced-choice trials (two trials with each sample), and one correct free-choice trial (for each sample). If an incorrect choice was made during the free-choice trial, another correction procedure was implemented in addition to the one described above: the same sample stimulus was re-presented in the next trial (increasing the total number of free-choice trials within a block). For this pigeon only, sessions comprised six correct free-choice trials (three with each sample) plus a variable number of incorrect free-choice trials. For instance, if two incorrect

Table 1

Summary of the experimental phases, change criteria, and number of session for individual subjects.

Experimental phases Conditions	Change criteria	Number of sessions		
		A1	A2	A3
Baseline				
Vary – 0.10 threshold	75% accuracy 5 sessions	7	76	32
Repeat – 2 reinforced seq.				
Vary Testing				
Threshold manipulation				
Vary – 0.15 threshold	No trend 5 sessions	5	5	6
Vary – 0.25 threshold				
Vary – 0.50 threshold	5	5	5	5
Vary – 0.75 threshold				
Vary – 1.00 threshold	–	–	–	6
Vary – 0.50 threshold				
Vary – 0.25 threshold	6	5	6	6
Vary – 0.15 threshold				
Baseline				
Vary – 0.10 threshold	75% accuracy 5 sessions	38	28	50
Repeat – 2 reinforced seq.				
Repeat Testing				
Reinforced seq. manipulation				
Repeat – 4 reinforced seq.	No trend 5 sessions	5	6	4*
Repeat – 8 reinforced seq.				
Repeat – 12 reinforced seq.	7	5	5	5
Repeat – 16 reinforced seq.				
Repeat – 12 reinforced seq.	–	5	–	–
Repeat – 8 reinforced seq.				
Repeat – 4 reinforced seq.	6	5	5	4*
Repeat – 4 reinforced seq.				
Baseline				
Vary – 0.10 threshold	5 sessions	5	5	5
Repeat – 2 reinforced seq.				

Note: seq., sequence.

* Four sessions were conducted due to experimenter error.

choices occurred after the Repeat sample, the total number of trials with this sample would increase from three (the minimum of correct trials) to five (i.e., the three required correct trials plus the two incorrect ones, resulting in an accuracy of 60% for this sample). This procedure was maintained throughout the study for this pigeon. All other procedural details (reinforcement, BO period, primary correction procedure) were similar to the described for the final MTS task.

2.3.4. Vary testing

A procedure similar to that described in Baseline was employed, except for the parametrical manipulation of the variability requirement (threshold) in the Vary sample. The contingency in effect during the Repeat sample remained unchanged during this phase. Threshold values were presented in an ascending, and next, in a descending order (see Table 1). Low threshold values (such as 0.10) establish high levels of behavioral variability for reinforcement, whereas a high threshold value (such as 1.0) allows any sequence (varied or repetitive ones) to be reinforced. The rationale for this manipulation was that requiring lower variability levels would decrease the disparity between the Vary and Repeat samples (because behavior in the Vary sample would resemble that in the Repeat sample), thus reducing their discriminability.

2.3.5. Repeat testing

A procedure similar to that described in Baseline was implemented in this phase, except for the parametrical manipulation of the number of sequences eligible for reinforcement in the Repeat sample. The contingency in effect during the Vary sample remained unchanged. The number of reinforced sequences in each condition was increased (ascending order), and then decreased (descending order), as shown in Table 1. In each test condition,

new sequences were added (or removed) to the pool of eligible sequences. Thus, in the four reinforced sequences condition, the two trained repeat sequences and two additional sequences were eligible for reinforcement. The new reinforced sequences were individually selected: in the ascending order, the new sequences comprised the next two most frequent sequences in the immediately previous condition; in the descending order, the same sequences were removed in each condition.

Following the same rationale applied to the Vary Testing, increasing the number of repeat sequences was intended to decrease the disparity between the Vary and Repeat samples (because behavior in the Repeat sample would gradually become more variable, and then resemble that in the Vary sample), thus again reducing the discriminability of the Vary and Repeat contingencies.

2.4. Miscellaneous details

Sessions were terminated after four-trial blocks (16 free-choices trials) were completed or 60 min had elapsed, whatever occurred first (but see the baseline procedure of pigeon A2). The preliminary training and Baseline phases were in effect until stable responding in the sample and choice parts of the MTS task were obtained (see Table 1). Stability was defined as the absence of a trend in the reinforcement rate obtained in the mixed Vary–Repeat schedule (sample), and a high choice accuracy (minimum of 75% of correct choices after each sample) for at least five consecutive sessions. For pigeon A2, the minimum degree of accuracy required to meet the stability criterion was 60%. During the testing phases, each condition (threshold or number of reinforced sequences) was in effect for five sessions unless there was a great discrepancy between data from the last two sessions, in which case one or two additional sessions were conducted. Subject A3 was exposed to only four sessions in two conditions of the Repeat Testing Phase due to an experimenter error (see Table 1).

The programmed probability of reinforcement, $p(S^R)$, during the sample-contingencies was manipulated to maintain the obtained probabilities of reinforcement similar between samples. Because reinforcement rates tended to be higher in the Repeat sample, the $p(S^R)$ for the repeat sequences was reduced during most conditions (except for the Vary Testing phase). The $p(S^R)$ in the Repeat sample was calculated separately for each pigeon and was changed, if necessary, at the beginning of each session – programmed values ranged between 0.7 and 0.95 during the baseline, and between 0.5 and 0.8 during the Repeat Testing phase. During the Vary Testing Phase, the $p(S^R)$ in the Repeat sample was set at 1.0, and the $p(S^R)$ in the Vary sample was reduced (with values ranging from 0.6 to 1.0 across different conditions), because the obtained reinforcement probabilities tended to be higher in the Vary than in the Repeat sample.

2.5. Data analyses

Five behavioral measures were analyzed during the sample component – that is, the sequence's uncertainty (U value), the probability of the two repeat sequences, response rates, reinforcement rates, and sample duration – and two behavioral measures were considered for the choice component – discrimination accuracy ($\log d$) and response bias ($\log b$). These measures were calculated as follows:

- (a) The U value is an index of overall sequence variability. It takes into account the likelihood of all sequences in a defined set of emitted sequences (e.g., a session). It is computed according to

the following equation (Miller and Frick, 1949):

$$\frac{\sum RFi \times [\log(RFi)/\log(2)]}{\log(16)/\log(2)}$$

where RF is the relative frequency of sequence i (for $i = 1$ to n), and n is the number of all possible sequences (16). If each of the 16 possible sequences were emitted equally often, then U would be equal to 1; if only one sequence was emitted, U would be equal to 0.

- (b) The probability of occurrence of the two trained repeat sequences was calculated in all experimental phases to examine changes in the specific behavior selected by the Repeat contingency. This measure was always computed by dividing the frequency of the two repeat sequences by the total number of sequences emitted (mean frequencies for each repeat sequence are provided in Appendix A).
- (c) Response rates (responses per minute), reinforcement rates (reinforcers per minute), and sample duration (in seconds) were measured for each session.
- (d) $\log d$, an empirical measure of discrimination accuracy (Davison and Tustin, 1978; Nevin et al., 2007), was computed according to the following equation:

$$\log d = 0.5 \times \log \frac{p(B_1/S_1) \times p(B_2/S_2)}{p(B_2/S_1) \times p(B_1/S_2)}$$

where p stands for probability, B_1 represents choice of the white key, B_2 represents choice of the green key, and S_1 and S_2 represent the Vary and Repeat samples, respectively. Thus, B_1/S_1 represents the probability of a white choice after the Vary sample (i.e., a correct choice), and B_2/S_1 represents the probability of a green choice after a Vary sample (i.e., an incorrect choice). $\log d$ can range from zero to infinity, with a value of zero showing the absence of discrimination.

- (e) $\log b$ is a measure of response bias (Davison and Tustin, 1978; Nevin et al., 2007). It ranges from zero to infinity, with a value of zero indicating no response bias. It is calculated according to the equation:

$$\log b = 0.5 \times \log \frac{p(B_1/S_1) \times p(B_1/S_2)}{p(B_2/S_1) \times p(B_2/S_2)}$$

where p , B_1 , B_2 , S_1 and S_2 represent the same measures as in the $\log d$ equation.

For each condition of the Vary and Repeat Testing phases, the U value, the probability of the trained repeat sequences, the $\log d$, and the $\log b$ were calculated by pooling together data from all sessions in that condition for each subject. For the Baseline phases, the last five sessions were used to calculate the respective measures. Accordingly, mean values for these same sessions were provided for the response and reinforcement rates, and sample duration.

For the sample performance, a positive difference in each measure between samples was considered as an indicative of sample disparity. Thus, if the U value in the Vary sample was 0.80 and the U value in the Repeat sample was 0.60, the disparity between samples was of 0.20. Likewise, if U values of 0.80 and 0.70 were obtained for the Vary and Repeat samples, the disparity would be of 0.10. Consequently, the closer the difference was to 0.0, the lower the sample disparity.

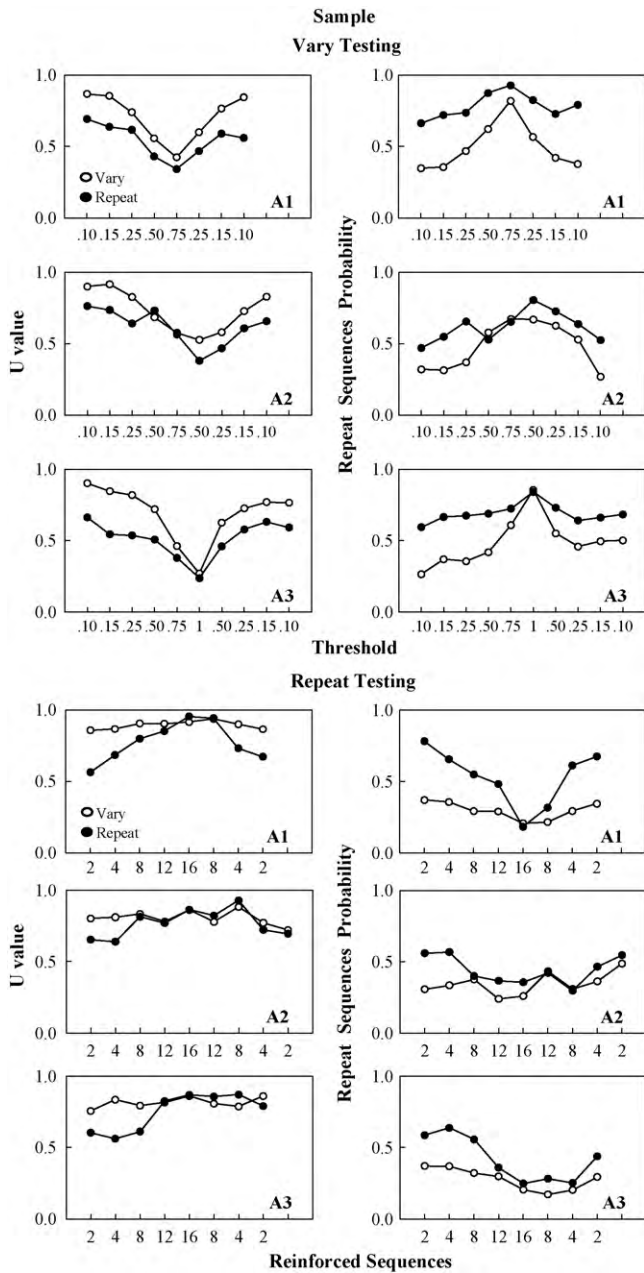


Fig. 2. The *U* value (left panels) and the probability of the repeat sequences (right panels) in the Vary (open symbols) and Repeat (black symbols) samples for each value of the parametric manipulation implemented in the Vary Testing (threshold) and in the Repeat Testing (number of reinforced sequences) phases. Rows present data of individual subjects.

3. Results

3.1. Sample performance

Fig. 2 presents the *U* value (left panels) and the probability of the two trained repeat sequences (right panels) for the Vary (open symbols) and Repeat (black symbols) samples in each condition of the Vary Testing and Repeat Testing phases. Baseline data are depicted as the first and last conditions of each testing phase.

During the Vary Testing, the *U* value (left panels on the top) was higher in the Vary than in the Repeat sample in almost all conditions. Increases (decreases) in the threshold were accompanied by decreases (increases) in the Vary and Repeat *U* values and in the disparity between samples. Conversely, the probability of the repeat

Table 2

Mean and standard deviation (SD) for response rate, reinforcer rate, and sample duration, in the Vary and Repeat samples, calculated for each subject in the Vary Testing (left columns) and Repeat Testing (right columns) phases.

Subject	Vary Testing		Repeat Testing		Vary sample	Repeat sample	Vary sample	Repeat sample
	Vary sample	Repeat sample	Vary sample	Repeat sample				
Measure	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
A1								
Response rate	41.3	(1.2)	41.3	(1.4)	41.6	(1.4)	41.7	(2.1)
Reinforcer rate	06.4	(1.5)	06.8	(1.0)	06.0	(1.0)	06.0	(1.1)
Sample duration	66.9	(2.8)	65.2	(1.8)	66.6	(2.2)	67.0	(3.6)
A2								
Response rate	37.2	(3.0)	39.4	(2.8)	33.4	(2.7)	34.0	(2.3)
Reinforcer rate	05.0	(1.5)	05.4	(1.6)	03.0	(0.8)	04.1	(1.0)
Sample duration	69.0	(6.0)	71.6	(6.6)	75.9	(6.8)	72.6	(5.7)
A3								
Response rate	39.1	(1.4)	39.2	(1.7)	32.2	(2.0)	33.0	(2.1)
Reinforcer rate	05.4	(1.3)	05.7	(1.1)	03.8	(0.7)	04.5	(1.3)
Sample duration	67.7	(2.9)	67.5	(3.3)	70.0	(3.2)	71.7	(6.9)

Note: The following measures were used: key-pecks per minute (response rate); reinforcers per minute (reinforcer rate); and seconds (sample duration).

sequences (right panels on the top) was lower in the Vary than in the Repeat sample in all conditions. In addition, increases (decreases) in the threshold were accompanied by increases (decreases) in the probability of the repeat sequences in both samples and decreases (increases) in the disparity between samples.

During the Repeat Testing (left panels on the bottom), the *U* value was higher in the Vary than in the Repeat sample in the first condition, replicating the data obtained in the baseline of the Vary Testing. Increasing the number of reinforced sequences increased the *U* value in the Repeat sample, but it did not systematically affect the *U* value in the Vary sample. Yet, this manipulation reduced the disparity between samples. Subsequent decreases in the number of reinforced sequences produced unsystematic effects. The *U* value was reduced in the Repeat sample for pigeons A1 and A2, and in the Vary sample for pigeon A2. In the remaining situations, *U* values were not affected. Thus sample disparity increased only for pigeon A1.

The probability of the repeat sequences tended to be lower in the Vary than in the Repeat sample during both baselines of the Repeat Testing Phase (right panels on the bottom). Increases in the number of reinforced sequences were accompanied by decreases in the probability of the two trained repeat sequences in the Repeat sample and, in a less consistent way, in the Vary sample. Accordingly, there was a decrease in sample disparity. With decreases in the number of reinforced sequences, the probability of the two repeat sequences tended to increase in both samples. As it was observed with the *U* value, the disparity between samples increased for pigeon A1, but not for pigeons A2 and A3.

Response rate, reinforcement rate, and sample duration were evaluated in both samples during all conditions of the Vary Testing and Repeat Testing phases. Mean and standard deviations (SD) for those measures are presented in Table 2. In general, for each measure, the means obtained in the Vary and Repeat samples were comparable (with low standard deviations) in both testing phases for all subjects.

Together, those results show that the Vary and Repeat samples were similar in all measures, but the level of behavioral variability. The Vary and Repeat contingencies in effect during the baseline produced differentiated variability levels, and manipulations in the variation criterion (i.e., during the Vary Testing) and in the repetition criterion (i.e., during the Repeat Testing) affected the variability levels in both samples, changing the degree of disparity between samples.

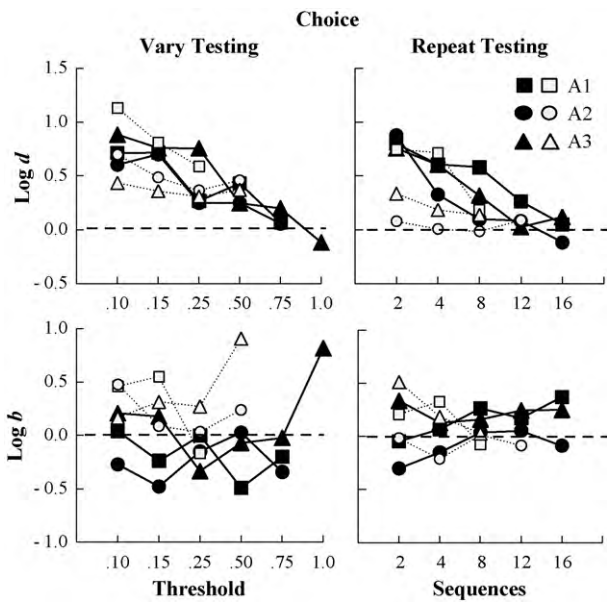


Fig. 3. Discrimination accuracy ($\log d$, top panels) and response bias ($\log b$, bottom panels) in each condition of the Vary Testing and Repeat Testing phases. Data are shown for individual subjects in the ascending (black symbols) and descending (light gray symbols) orders of exposure to the threshold values and to the number of reinforced sequences.

3.2. Choice performance

Fig. 3 presents the $\log d$ (upper panel) and $\log b$ (lower panel) obtained in the ascending (black symbols) and descending (light gray symbols) order of exposure to the values of the threshold (i.e., in the Vary Testing) and to the number of reinforced sequences (i.e., in the Repeat Testing) for each subject.

During the Vary Testing, $\log d$ was higher during the baseline (first condition) and decreased (and then increased) with increases (and decreases) in the threshold. During the Repeat Testing, increasing the number of reinforced sequences was followed by consistent decreases in $\log d$, as happened with increases in the threshold. Decreasing the number of reinforced sequences increased $\log d$ values for pigeon A1, and to a less extent for pigeon A3, but did not improve discrimination accuracy for pigeon A2.

$\log b$ values ranged from -0.5 to 0.5 in the baseline phases for all subjects, suggesting low response bias. Moreover, $\log b$ was not systematically affected by varying the values of the threshold (Vary Testing) and the number of reinforced sequences (Repeat Testing). Only pigeon A3 presented bias values above 0.5 . Inspection of this pigeon's data showed choice bias towards the white key in the 1.0 -threshold condition and in the subsequent 0.50 -threshold condition (data not shown).

To evaluate which sample variable was indeed controlling choice, the disparity (i.e., the positive difference) between the Vary and Repeat samples with respect to the U value, probability of the trained repeat sequences, response rate, reinforcer rate, and sample duration was plotted against discrimination accuracy ($\log d$), for each condition of the testing phases. Fig. 4 shows the dispersion graphs for each of those measures as a function of $\log d$. Solid lines are fitted least-squared regression lines. The equation ($y = ax + b$) and fit (R^2) are also presented.

As can be seen in Fig. 4, $\log d$ increased as the disparity in variability measures (U value and probability of the repeat sequences) increased, but was not affected by disparity in the other measures. The regression analysis corroborates the visual trend: high slope values (a) were obtained for the U value and probability of the repeat sequences, whereas low slope values (close to 0.0) were

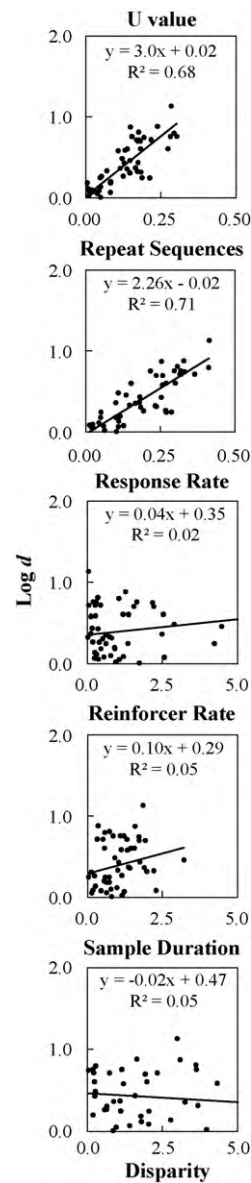


Fig. 4. $\log d$ plotted as a function of the disparity (positive difference) between the Vary and the Repeat samples with respect to the U value, the probability of the trained repeat sequences, the response rate, the reinforcement rate, and the sample duration. Data points comprise all conditions of the Vary Testing and Repeat Testing phases for all subjects.

obtained for the other measures. The R^2 was also relatively high for the variability measures (0.68 and 0.70) and low (ranging from 0.02 to 0.05) for the other measures. These results indicate that changes in discrimination accuracy may be accounted for the disparity in the variability levels between samples.

A stepwise regression analysis was performed using $\log d$ as the dependent variable and the disparities in all sample measures as independent variables. The stepwise regression revealed that the disparity in the repeat sequences alone was a good predictor of the variance of $\log d$ ($R^2_{\text{adj}} = .683$, $\beta = .830$, $p < .001$), and that the overall fit increased when the disparity of the U value was added as predictor ($R^2_{\text{adj}} = .746$). None of the other variables significantly improved the model and were dropped. Hence, the final model included the disparities in the probability of the repeat sequences ($\beta = .482$, $p < .001$) and in the U value ($\beta = .433$, $p = .001$). The analysis of variance (ANOVA) revealed that the overall model was significant, $F(2, 49) = 75.713$, $p < .001$. The standardized regression

equation is therefore:

$$y(\log d) = \underset{(0.04)}{-0.03} + \underset{(0.32)}{1.31} \times RSeqDisp + \underset{(0.40)}{1.47} \times UDisp$$

where *RSeqDisp* stands for the disparity in the repeat sequences probability and *UDisp* for the disparity in the *U* value between samples. Standard deviation values are presented in parenthesis.

4. Discussion

The present findings are consistent with the interpretation that R–S contingencies alter the level of behavioral variability displayed by an organism. More importantly, our findings show that those contingencies may serve discriminative functions for subsequent choice behavior.

As it was observed in Fig. 2, the Vary and Repeat contingencies controlled high and low levels of behavioral variability, respectively, during the baseline phases. This result challenges the argument that variability is simply elicited by adversity in reinforcement conditions (i.e., extinction or reductions in the probability of reinforcement), and supports the interpretation that variation and repetition can be learned skills under the control of their consequences – that is, operant behaviors (e.g., Neuringer, 2002, 2004; Page and Neuringer, 1985).

Considering that the programmed Vary and Repeat contingencies not only generated differentiated levels of behavioral variability, but also that they did so in the absence of (antecedent) exteroceptive cues, our results, together with those reported by Hopson et al. (cited by Neuringer, 2002), must be taken as evidence that operant contingencies can function as discriminative stimuli for varying over repeating. Our findings, however, are more persuasive than those of Hopson et al., because we parametrically manipulated the variation and repetition requirements across conditions. Decreases and increases in the requirement of variation (i.e., threshold) during the Vary Testing produced corresponding decreases and increases in the variability displayed in the Vary and Repeat samples. In addition, decreases and increases in the requirement of repetition (i.e., the number of reinforced sequences) during the Repeat Testing were followed by decreases and increases in the variability levels displayed, at least for pigeon A1, during the Repeat sample. Overall, these results indicate that variability levels were under the control of the programmed contingencies. This demonstration replicates previous studies that employed between-subject (e.g., Grunow and Neuringer, 2002; Machado, 1989; Page and Neuringer, 1985; Wagner and Neuringer, 2006) or within-subject (e.g., Abreu-Rodrigues et al., 2005; Stokes, 1999) designs. Moreover, these results suggest that variation and repetition are not dichotomous behavioral classes, and that they must be better understood by means of the notion of a continuum, with high variation at one end point and strict repetition at the other (Neuringer, 2002; Stokes, 1999).

Furthermore, changing the variability and repetition requirements did not only change the variability levels, but it made the behavior displayed between samples more similar (low sample disparity). For example, loosening the vary requirement made subjects to vary less (as shown by the *U* value). In this situation, subjects could have started to emit any of the possible sequences more often (especially more easy sequences as LLLL and RRRR); however, the sequences that increased in frequency were the repeat ones (as shown by the two repeat sequences probability). Since these sequences were also eligible for reinforcement in the Vary sample, it became more difficult for the subjects to discriminate whether they had experienced a Vary or a Repeat sample. Likewise, when the requirement in the Repeat sample was made more easy to meet (by increasing the number of acceptable sequences), the probability of the repeat sequences decreased and the *U* value increased

– even though reinforcers could still be earned by emitting solely the repeat sequences or by emitting only the most easy sequences (LLLL or RRRR) – thus suggesting that subjects were behaving like in the Vary sample. All in all, changing the requirement of either contingency reduced the disparity between contingencies probably because similar responses could be emitted under both contingencies (since the same set of sequences were in effect), and interaction effects were more probable given this response overlap.

Interestingly, the results of the present study showed that the variability displayed in the Repeat sample was affected by the manipulation in the requirement of variation in the Vary sample (Vary Testing), but the variability during the Vary sample was not affected by changes in the requirement of repetition in the Repeat sample (Repeat Testing), as shown in Fig. 2. The interaction between the Vary and Repeat contingencies during the Vary Testing may have occurred because of the absence of discriminative cues signaling which contingency was in effect (e.g., Hanna et al., 1992). The fact that this interaction was observed only during the Vary Testing could be indicative that repetition was more sensitive to contingency changes than variation. Indeed, there is a considerable amount of evidence that repetitive behaviors are more susceptible to interfering events than varied ones (e.g., Abreu-Rodrigues et al., 2004; Neuringer et al., 2001; Odum et al., 2006; Wagner and Neuringer, 2006; Ward et al., 2006). However, it is also possible that the Vary performance was unaffected during the Repeat Testing because of a ceiling effect – variability was already so high in the Vary sample that the effect of any variable that would further promote increases in variability was hard to detect. To clear this issue, future research may examine interactions between Vary and Repeat contingencies under mixed schedules by employing requirements that select intermediate variability levels.

A number of studies have evaluated the effects of the disparity between sample-contingencies upon discrimination accuracy. For example, Shimp (1981, 1983) used contingencies that required different inter-response intervals (IRTs) and Hobson (1975), Pliskoff and Goldiamond (1966), and Rilling and McDiarmid (1965) used two FR schedules as sample stimuli. They observed a direct relation between sample disparity and discrimination accuracy. Similarly, in the present study, as the variability levels in the Vary and Repeat samples became progressively similar (low disparity), discrimination accuracy decreased; and as they became progressively dissimilar (high disparity), discrimination accuracy increased (see Fig. 4). These results suggest that the degree of behavioral variation functioned as a discriminative stimulus for choice.

This suggestion seems stronger when the effects of additional variables are considered. Several studies have indicated that response rate (e.g., Lionello-DeNolf and Urcuioli, 2003; Okouchi and Songmi, 2004; Urcuioli and DeMarse, 1994), reinforcement rate (e.g., Commons, 1979), and sample duration (e.g., Reynolds and Catania, 1962) may serve discriminative functions in MTS tasks. In the present study, as it was shown in Table 2, response rates, reinforcer rates, and sample durations were not consistently different between the Vary and Repeat samples, thus minimizing the chance that those variables were functioning as cues for accurate choices. In contrast, the variability measures (i.e., the *U* value and the repeat sequences' probability) were systematically different between samples, becoming a more probable candidate as controlling stimuli. In accordance with this interpretation, when the differences between the measures of sample performance were plotted against the $\log d$ (Fig. 4), only the variability measures were found to be related to the changes observed in discrimination accuracy, and the stepwise regression showed that those variables accounted for a great part of the variability in $\log d$.

Changing the variation and repetition criterion did not consistently affect response bias (see Fig. 3). These data are consistent with previous studies in which no reliable effects of manipulations

in the distinctiveness of sample-contingencies upon log *b* values were observed (see Davison and Nevin, 1999 for a review). In the studies discussed by Davison and Nevin, when response bias was obtained, it was usually a function of differential reinforcement rates between contingencies (either in the sample or choice components). For this reason, in the present study, as similar reinforcement rates were provided under the Vary and Repeat samples, and the ratio of reinforcement was equal between the two-choice components of the MTS task, it was not surprising that response bias was either low or absent across most conditions.

Furthermore, it might be worth noticing that providing reinforcement during the sample component is not the usual procedure in the contingency discrimination literature. Usually, meeting the sample contingency requirement produces the opportunity to choose between comparisons (a conditioned reinforcer). Nevertheless, some studies have employed reinforcement during the sample-contingencies (e.g., Commons, 1979; Jones and Davison, 1998; Lattal, 1979). In the study of Lattal (1979), for example, conditions with and without reinforcement during the sample were compared and this variable did not affect discrimination. Differential reinforcement rates between samples, though, might have an effect upon discrimination accuracy (e.g., Jones and Davison, 1998). However, as we stated above, similar obtained reinforcement rates were programmed during the sample. Therefore, we did not expect the degree of discrimination accuracy obtained in the present study to be different from the one obtained in other procedures in which conditioned reinforcers are employed.

The findings reported here are consistent with the hypothesis that R-S contingencies can serve the dual function of reinforcing variation over repetition and of signaling when varying or repeating is the more efficient behavior pattern. Furthermore, the discriminative function exerted by those contingencies seems to be comparable to the one exerted by exteroceptive stimuli. Wasserman et al. (2004), in reviewing studies on how humans and non-humans make a same-different judgment, pointed out that such judgment was effectively controlled by variety (or, we could say, disparity) in a set of exteroceptive stimuli. For example, in some of the studies described by those authors, a number of stimuli (e.g., a set of 12 stimuli) were presented on a screen. In some trials, all stimuli were the same, while in other trials the number of different stimuli (out of 12) was gradually increased, thus reducing the disparity between these sets. The probability of giving a 'different' response was found to increase with the number of different stimuli presented to both humans and non-humans (pigeons and baboons), thus suggesting that increasing the disparity in the stimuli set produced higher discrimination accuracy. Likewise, in the present study, the probability of reporting a Vary or a Repeat sample was affected by the disparity in the behavioral variability displayed between samples. Taken together, our findings and those reviewed by Wasserman et al. suggest that humans and non-humans can learn to discriminate non-behavioral events as well as aspects of their own behavior in a similar way.

In sum, the present experiment further support the interpretation of behavioral variability as an operant. As outlined in the introduction, variability levels can be adaptive, and organisms can learn to increase and decrease their own variability levels in order to better attend a contingency requirement. Additionally, organisms can accurately report whether their behavior was varied or repetitive. The present results indicate that this discrimination can be under control of the contingencies (behavior-reinforcer relation) in a similar manner to the control exerted by exteroceptive stimuli (stimulus-reinforcer relations). In other words, variability discrimination is not only restricted to exteroceptive stimuli relations, but also comprises the discrimination of variability levels in an organism's own behavior.

Acknowledgements

Part of this researched was derived from a master thesis presented by the first author to the Universidade de Brasília under the supervision of the second author. This research was supported by a scholarship provided to the first author by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

Portions of these data were presented in the 32nd Annual Convention of the Association for Behavior Analysis (Atlanta, 2006) and in the XV Encontro Brasileiro de Psicoterapia e Medicina Comportamental (Brasília, 2006).

We would like to thank Júnina Moreira, Pablo Cardoso, Juliana Vilela, and specially, Virginia Fava and Roberta Ladislau, for their help in collecting portions of the data. Furthermore, we would like to thank Allen Neuringer and an anonymous reviewer for their valuable comments and suggestions on an earlier draft of this paper.

Appendix A.

Mean, maximum, and minimum probabilities for each of the two trained repeat sequences **in the Vary and Repeat samples** during the Vary and Repeat Testing phases (baseline phases included).

	Vary Testing				Repeat Testing			
	Vary		Repeat		Vary		Repeat	
	RLLL	RRLl	RLlL	RLLl	RLLL	RRLl	RLlL	RLLl
A1								
Mean	0.24	0.26	0.41	0.37	0.16	0.14	0.34	0.20
Max	0.48	0.37	0.56	0.49	0.18	0.19	0.47	0.31
Min	0.14	0.19	0.30	0.27	0.12	0.08	0.12	0.06
	Vary Testing				Repeat Testing			
	Vary		Repeat		Vary		Repeat	
	LRLR	LRRR	LRlR	LRRR	LRLR	LRRR	LRlR	LRRR
A2								
Mean	0.10	0.41	0.08	0.55	0.12	0.23	0.10	0.33
Max	0.12	0.57	0.13	0.75	0.14	0.38	0.13	0.49
Min	0.06	0.19	0.06	0.37	0.09	0.13	0.07	0.19
	Vary Testing				Repeat Testing			
	Vary		Repeat		Vary		Repeat	
	RLLL	LLRR	RLlL	LLRR	RLLL	LLRR	RLlL	LLRR
A3								
Mean	0.44	0.09	0.64	0.07	0.21	0.05	0.32	0.04
Max	0.80	0.20	0.84	0.15	0.36	0.08	0.61	0.06
Min	0.18	0.00	0.51	0.00	0.15	0.01	0.21	0.02

References

- Abreu-Rodrigues, J., Hanna, E.S., Cruz, A.P.M., Matos, R., Delabrida, Z., 2004. Differential effects of midazolam and pentylentetrazole on behavioral repetition and variation. *Behav. Pharmacol.* 15, 535–543.
- Abreu-Rodrigues, J., Lattal, K.A., Santos, C.V., Matos, R.A., 2005. Variation, repetition, and choice. *J. Exp. Anal. Behav.* 83, 147–168.
- Cohen, L., Neuringer, A., Rhodes, D., 1990. Effects of ethanol on reinforced variations and repetitions by rats under a multiple schedule. *J. Exp. Anal. Behav.* 54, 1–12.
- Commons, M.L., 1979. Decision rules and signal detectability in a reinforcement-density discrimination. *J. Exp. Anal. Behav.* 83, 101–120.
- Davison, M., Nevin, J.A., 1999. Stimuli, reinforcers, and behavior: an integration. *J. Exp. Anal. Behav.* 71, 439–482.
- Davison, M.C., Tustin, R.D., 1978. The relation between the generalized matching law and signal-detection theory. *J. Exp. Anal. Behav.* 29, 331–336.
- Denney, J., Neuringer, A., 1998. Behavioral variability is controlled by discriminative stimuli. *Anim. Learn. Behav.* 26, 154–162.
- García, A.G., Rodríguez, S.B., 2006. Discriminación condicional de la propia conducta en palomas: el papel de la longitud de la conducta-muestra (Conditional discrimination of one own's behavior in pigeon: the role of the length of the behavior-sample). *Int. J. Psych. Psychol. Ther.* 6, 331–342.

- Grunow, A., Neuringer, A., 2002. Learning to vary and varying to learn. *Psychon. Bull. Rev.* 9, 250–258.
- Hanna, E.S., Blackman, D.E., Todorov, J.C., 1992. Stimulus effects on concurrent performance in transition. *J. Exp. Anal. Behav.* 58, 335–347.
- Hartl, J.A., Dougherty, D.H., Wixted, J.T., 1996. Separating the effects of trial-specific and average sample-stimulus duration in delayed matching to sample in pigeons. *J. Exp. Anal. Behav.* 66, 231–242.
- Hobson, S.L., 1975. Discriminability of fixed-ratio schedules for pigeons: effects of absolute ratio size. *J. Exp. Anal. Behav.* 23, 25–35.
- Jones, B.M., Davison, M., 1998. Reporting contingencies of reinforcement in concurrent schedules. *J. Exp. Anal. Behav.* 69, 161–183.
- Killeen, P.R., 1978. Superstition: a matter of bias, not detectability. *Science* 199, 88–90.
- Lattal, K.A., 1975. Reinforcement contingencies as discriminative stimuli. *J. Exp. Anal. Behav.* 23, 241–246.
- Lattal, K.A., 1979. Reinforcement contingencies as discriminative stimuli: II. Effects of changes in stimulus probability. *J. Exp. Anal. Behav.* 31, 15–22.
- Lionello-DeNolf, K.M., Urciuoli, P.J., 2003. A procedure for generating differential "sample" responding without different exteroceptive stimuli. *J. Exp. Anal. Behav.* 79, 21–35.
- Machado, A., 1989. Operant conditioning of behavioral variability using a percentile reinforcement schedule. *J. Exp. Anal. Behav.* 52, 155–166.
- Miller, G.A., Frick, F.C., 1949. Statistical behavioristics and sequences of responses. *Psychol. Rev.* 56, 311–324.
- Nelson, K.R., Wasserman, E., 1978. Temporal factors influencing the pigeon's successive matching-to-sample performance: Sample duration, intertrial interval, and retention interval. *J. Exp. Anal. Behav.* 30, 153–162.
- Neuringer, A., 1986. Can people behave "randomly?": the role of feedback. *J. Exp. Psychol.: Gen.* 115, 62–75.
- Neuringer, A., 2002. Operant variability: evidence, functions, and theory. *Psychon. Bull. Rev.* 9, 672–705.
- Neuringer, A., 2004. Reinforced variability in animals and people: implications for adaptive action. *Am. Psychol.* 59, 891–906.
- Neuringer, A., Kornell, N., Olufs, M., 2001. Stability and variability in extinction. *J. Exp. Psychol.: Anim. Behav. Process.* 27, 79–94.
- Nevin, J.A., Davison, M., Odum, A.L., Shahan, T.A., 2007. A theory of attending, remembering, and reinforcement in delayed matching to sample. *J. Exp. Anal. Behav.* 88, 285–317.
- Odum, A.L., Ward, R.D., 2004. The effects of morphine on the production and discrimination of interresponse times. *J. Exp. Anal. Behav.* 82, 197–212.
- Odum, A.L., Ward, R.D., Barnes, C.A., Burke, K.A., 2006. The effects of delayed reinforcement on variability and repetition of response sequences. *J. Exp. Anal. Behav.* 86, 159–179.
- Okouchi, H., 2003. Effects of differences in interreinforcer intervals between past and current schedules on fixed-interval responding. *J. Exp. Anal. Behav.* 79, 49–64.
- Okouchi, H., Songmi, K., 2004. Differential reinforcement of human self-reports about schedule performances. *Psychol. Rec.* 54, 461–478.
- Page, S., Neuringer, A., 1985. Variability is an operant. *J. Exp. Psychol.: Anim. Behav. Process.* 11, 429–452.
- Pliskoff, S.S., Goldiamond, I., 1966. Some discriminative properties of fixed ratio performance in the pigeon. *J. Exp. Anal. Behav.* 9, 1–9.
- Reynolds, G.S., 1966. Discrimination and emission of temporal intervals by pigeons. *J. Exp. Anal. Behav.* 9, 65–68.
- Reynolds, G.S., Catania, A.C., 1962. Temporal discrimination in pigeons. *Science* 135, 314–315.
- Rilling, M., McDiarmid, C., 1965. Signal detection in fixed-ratio schedules. *Science* 148, 526–527.
- Shimp, C.P., 1981. The local organization of behavior: discrimination of and memory for simple behavioral patterns. *J. Exp. Anal. Behav.* 36, 303–315.
- Shimp, C.P., 1982. On metaknowledge in the pigeon: an organism's knowledge about its own behavior. *Anim. Learn. Behav.* 10, 358–364.
- Shimp, C.P., 1983. The local organization of behavior: dissociations between a pigeon's behavior and self-reports of that behavior. *J. Exp. Anal. Behav.* 39, 61–68.
- Stokes, P.D., 1999. Learned variability levels: implications for creativity. *Creativity Res. J.* 12, 37–45.
- Urciuoli, P.J., DeMarse, T., 1994. On the relationship between differential outcomes and differential sample responding in matching-to-sample. *J. Exp. Psychol.: Anim. Behav. Process.* 20, 249–263.
- Urciuoli, P.J., DeMarse, T.B., Lionello, K.M., 1999. Sample-duration effects on pigeons' delayed matching as a function of predictability of duration. *J. Exp. Anal. Behav.* 72, 279–297.
- Wagner, K., Neuringer, A., 2006. Operant variability when reinforcement is delayed. *Learn. Behav.* 34, 111–123.
- Ward, R.D., Bailey, E.M., Odum, A.L., 2006. Effects of *d*-amphetamine and ethanol on variable and repetitive key-peck sequences in pigeons. *J. Exp. Anal. Behav.* 86, 285–305.
- Ward, R.D., Kynaston, A.D., Bailey, E.M., Odum, A.L., 2008. Discriminative control of variability: effects of successive stimulus reversals. *Behav. Process.* 78, 17–24.
- Wasserman, E.A., Young, M.E., Cook, R.G., 2004. Variability discrimination in humans and animals: implications for adaptive action. *Am. Psychol.* 59, 879–890.
- Zentall, T.R., Clement, T.S., Bhatt, R.S., Allen, J., 2001. Episodic-like memory in pigeon. *Psychon. Bull. Rev.* 8, 685–690.
- Ziriax, J.M., Silberberg, A., 1978. Discrimination and emission of different key-peck durations in the pigeon. *J. Exp. Psychol.: Anim. Behav. Process.* 4, 1–21.