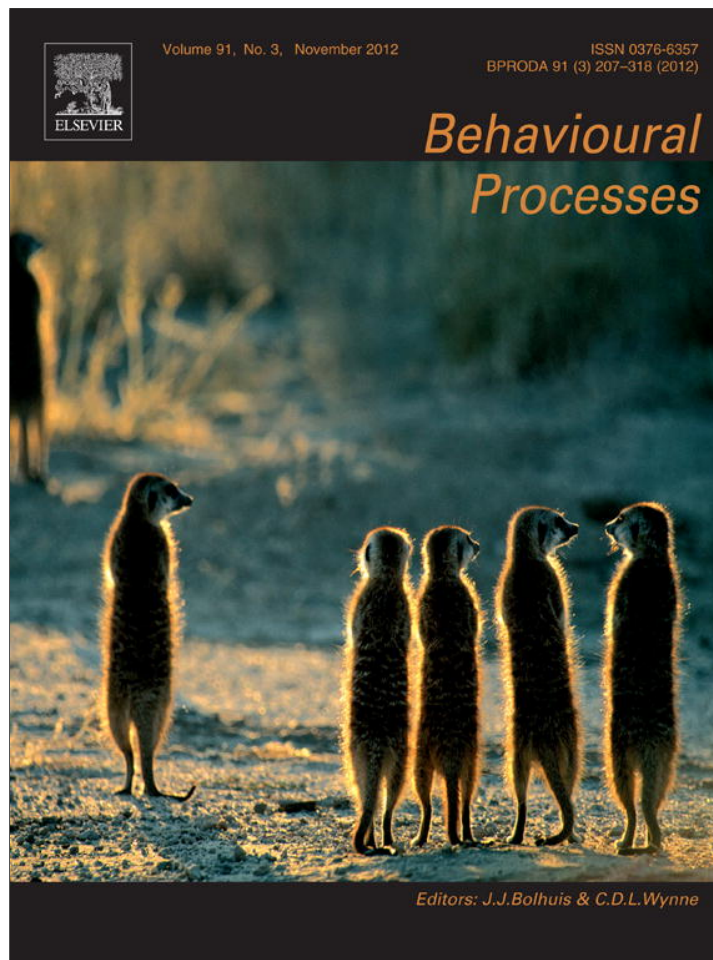


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Review

Choice between contingencies of variation: Effects of the requirement of variation upon preference

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ABSTRACT

The present study investigated whether choices between contingencies of variation are affected by the degree of variability required. For such, five pigeons were exposed to a concurrent chain schedule. In the initial links, responses in one key initiated the terminal link with the most stringent variation requirement while responses in the other key initiated the terminal link with the least stringent variation requirement. In both terminal links, four-responses sequences were reinforced according to a variation criterion, which favored less frequent and less recent sequences. The probability of reinforcement in the terminal link with the least stringent criterion was manipulated in order to generate similar percentage and rate of reinforcers in both terminal links. Choices for the terminal link with the least stringent criterion were more frequent than choices for the terminal link with the most stringent criterion. It is possible that situations that demand lower levels of behavior variability are chosen due to the lower response cost correlated to those situations.

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Contents

1. Introduction.....	214
2. Materials and methods.....	215
2.1. Subjects.....	215
2.2. Apparatus.....	215
2.3. Procedure.....	215
2.3.1. Pretraining.....	215
2.3.2. Concurrent-chains schedule.....	216
3. Data analyses.....	217
4. Results.....	218
4.1. Terminal links.....	218
4.2. Initial links.....	219
5. Discussion.....	220
5.1. <i>U</i> values.....	221
5.2. Number of switches per sequence.....	221
5.3. Choice.....	221
Acknowledgements.....	222
References.....	222

1. Introduction

Operant variability has been defined as a dimension or property of a behavior universe, and like other behavioral dimensions (e.g., force, duration, latency and topography), it may be selected by reinforcement contingencies (Abreu-Rodrigues, 2005; Hunziker

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and Moreno, 2000; Page and Neuringer, 1985). More specifically, behavioral variation increases directly with the degree of variability required for reinforcement (e.g., Abreu-Rodrigues et al., 2005, 2007; Grunow and Neuringer, 2002; Odum et al., 2006; Page and Neuringer, 1985; Stokes, 1999), and it may come under the control of exteroceptive (e.g., Cohen et al., 1990; Denney and Neuringer, 1998; Page and Neuringer, 1985) and interoceptive discriminative stimuli (Souza and Abreu-Rodrigues, 2010).

Variation has been studied in the context of choice. For example, Neuringer (1992) evaluated whether choices between variation and repetition would be affected by the probability of reinforcement. Pigeons were exposed to vary and repeat contingencies. For each trial, the computer selected which contingency would be in effect. When the vary contingency was selected, the current sequence of four responses would be reinforced if it differed from the three previous ones. If the repeat contingency was selected, the current sequence should be equal to any one of the previous three sequences. The probability of reinforcement for varying and repeating was manipulated across experimental conditions such that the sum of both probabilities was always equal to 1.0. The percentages of varied sequences changed directly with the probability of reinforcement for varying, therefore indicating that choice between varying and repeating is affected by reinforcement probability.

Abreu-Rodrigues et al. (2005), however, noted that, in Neuringer's (1992) study, the index of preference (i.e., the ratio of varied to repeated sequences) was confounded with the direct action of reinforcement. That is, the greater number of varied sequences, as compared to repeated sequences, may indicate preference for variation, or it may be only an effect of the greater probability of reinforcers for varying than for repeating. To avoid this confounding effect, Abreu-Rodrigues et al. used concurrent-chains schedules. This schedule provides an index of preference (i.e., relative response rates in the initial links) that is clearly separated from the response patterns engendered by the reinforcement contingencies in the terminal links. Also, instead of manipulating the probability of reinforcement, they manipulated the degree of behavioral variability required by the vary contingency. In the initial links, it was in effect a concurrent-chains schedule VI 30 s VI 30 s. Responses in one key initiated the Repeat terminal link and responses in the other key initiated the Vary terminal link. During the terminal links, pigeons had to emit sequences of four responses distributed between a left (L) and a right (R) key. In the Repeat terminal link, reinforcers were contingent on the occurrence of a single sequence (LRRR) whereas in the Vary terminal link, reinforcers followed a sequence if it differed from the previous n sequences (lag criterion). In Experiment 1, three lag criteria were used across conditions (Lag 1, 5, and 10). Each terminal link was in effect until five reinforcers were obtained. Because vary contingencies tend to generate a greater number of non-criterion sequences than the repeat contingency, the rate of reinforcement tends to be lower in the former than in the latter contingency. To avoid any possible confounding effect of reinforcement rate, the durations of both terminal links were equated by adding a timeout at the end of the Repeat terminal link (Experiment 1) or by yoking the inter-reinforcement intervals (IRIs) in the Repeat terminal link to those in the Vary terminal link (Experiment 2). The results indicated that choices for the Repeat contingency tended to increase directly with the lag criterion. In other words, the greater the degree of variability required in the Vary terminal link, the greater the choice for the Repeat terminal link. Abreu-Rodrigues et al. (2007) replicated this procedure with college students and obtained similar results.

However, the results obtained by Abreu-Rodrigues and collaborators (2005, 2007) may be questioned. As mentioned before, the authors attempted to equate the rate of reinforcement in the Vary and Repeat terminal links by adding a timeout or by yoking the IRIs. Those strategies were successful in generating

similar reinforcement rates across terminal links, but the same did not occur with respect to the percentage of reinforcers, which was lower in the Vary terminal link. The critical point is that increases in the degree of variability required for reinforcement were accompanied by lower percentage of reinforcers. Hence, it is difficult to identify whether preference for the repeat contingency was determined by the variation requirement, the percentage of reinforcers, or both variables.

The purpose of the present study was to better evaluate the controlling properties of the variation requirement upon choice. For such, the rate and the percentage of reinforcers were maintained similar across the terminal links of a concurrent-chains schedule. Also, the present study extends those of Abreu-Rodrigues et al. (2005) and Abreu-Rodrigues et al. (2007), in which the focus was upon choice between vary and repeat contingencies, as long as it investigates choice between two vary contingencies which differed in terms of the variation requirement. Thus, in one terminal link the variation requirement was more stringent than in the other terminal link.

2. Materials and methods

2.1. Subjects

Five homing pigeons, two with an experimental history of variation and repetition (T02 and T05) and three (T01, T03 and T04) with unknown histories were maintained at 80% of their free-feeding weights throughout the experiment. They were housed individually with free access to water in a room with a 12:12 h light/dark cycle. Supplementary food was given 1 h after the end of the session for those subjects who were below their prescribed weights.

2.2. Apparatus

The experimental chamber had a workspace measuring 30 cm long, 33 cm deep, and 28 cm high. Three 3-cm diameter keys were displayed horizontally on the work panel, with 3 cm separating each other. Only the left key and the center key (hereafter called right key) were operative during the experiment. These two keys were transilluminated by red, white, or green lights. A Gerbrand food magazine delivered mixed grain through an aperture (4 cm × 4 cm) centered in the middle of the work panel and located 4.5 cm above the floor. A white houselight located in the center of the ceiling illuminated the chamber. The houselight and the keys were darkened and inoperative during 2-s grain presentations, when the hopper was illuminated by a white light. The chamber was housed in a light box equipped with a fan for ventilation and masking noise. A 486 DX2 40 MHz microcomputer, connected to the chamber by a MED-PC® interface system, arranged the experimental conditions and recorded the pigeons' responding. MED-PC® software was used to program the experimental contingencies.

2.3. Procedure

Sessions were conducted daily, five or six days a week at approximately the same time.

2.3.1. Pretraining

Due to their unknown experimental histories, pigeons T01, T03, and T04 were exposed initially to a shaping procedure, in which pecks on the left (L) and right (R) keys, both illuminated with the same color, were reinforced with 2-s access to mixed grain. Each key color was presented 20 times per session. After reliable key pecking on either key was obtained, which happened within one or two sessions, those subjects were exposed to a modified fixed-ratio (FR) 4 schedule, during which four-peck sequences were

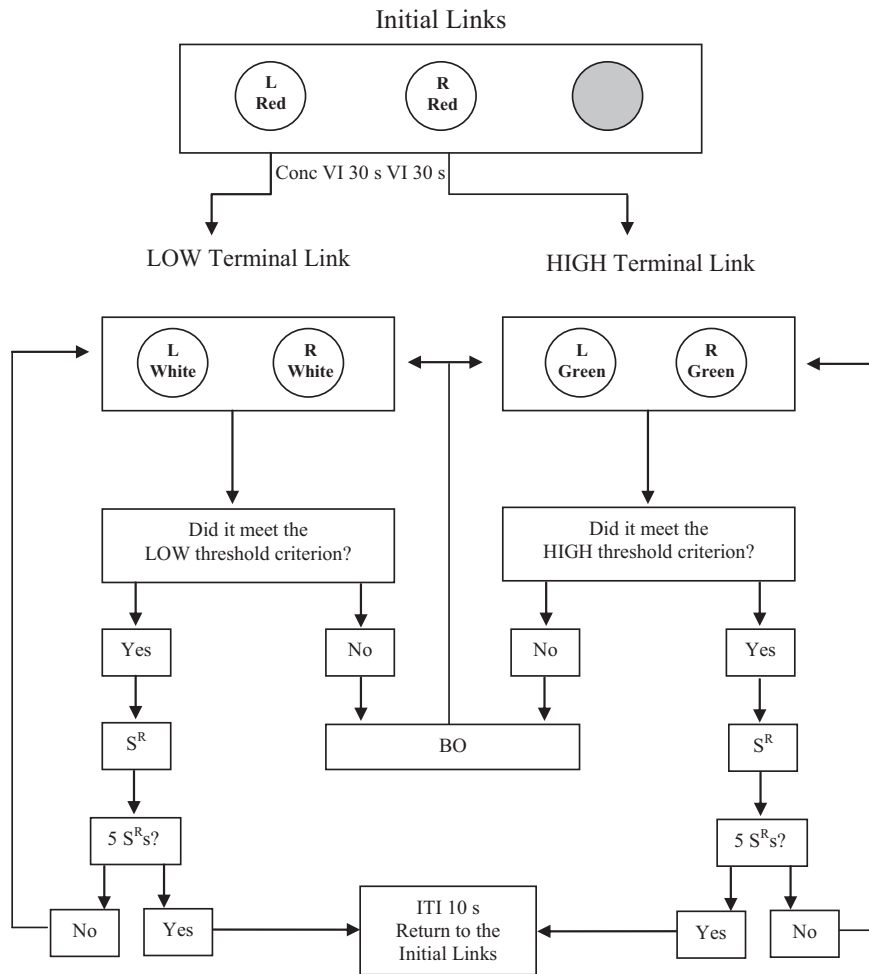


Fig. 1. Schematic diagram of the concurrent-chains schedule in the differential conditions. In the non-differential conditions, LOW criteria were used in both terminal links (L = left; R = right; S^R = reinforcer; BO = blackout; ITI = interreinforcer interval).

required for reinforcement. The four responses could be emitted on the same key or distributed across the left and right keys. Sessions were finished after the delivery of 60 reinforcers. This schedule was in effect for six (pigeon T01) or seven (pigeons T03 and T04) sessions. Because pigeons T02 and T05 had a recent experimental history with four-pecking sequences, no preliminary training was necessary.

2.3.2. Concurrent-chains schedule

Fig. 1 illustrates the concurrent-chains schedule used in the present study. In the initial links (ILs), the left and right keys were lit red, and pecks on those keys changed the color and initiated the terminal links (TLs). Entrances in the terminal links (TLs) were arranged according to a concurrent variable-interval (VI) 30-s VI 30-s schedule. The VI schedules operated as follows. Each VI schedule comprised 12 intervals. At the onset of the ILs, the computer selected in a pseudorandom manner one of the 12 intervals, and assigned it with equal probability to either the left key or the right key. Therefore, after an average of 30 s, a single peck on the assigned key initiated the corresponding TL; pecks on the non-assigned key were ineffective. The VI timer operated only during the ILs.

A left-key choice after the VI was timed-out changed the color of the left and right keys to white whereas a right-key choice changed the color of both keys to green. Under both TLs, each trial consisted of a sequence of four pecks distributed across left and right keys. There were 16 possible sequences (e.g., LRRR, RLLL, LLLL, and so on). Each of the first three key pecks turned the keylights off

for a 0.5-s period. Pecks during this period reset it and were not counted toward the sequence requirement. The fourth peck was followed either by 2-s access to mixed grain (i.e., a reinforcer) or by a 2-s blackout (BO), during which all lights were turned off. A new trial began immediately after a reinforcer delivery or a BO. Each TL remained in effect until five reinforcers were obtained. After that, a 10-s intertrial interval occurred and another IL was presented.

Two vary contingencies were available in the TLs. In both, infrequently occurring sequences were required for reinforcement. A sequence was reinforced if its weighted relative frequency was less than or equal to a threshold value (Denney and Neuringer, 1998; Grunow and Neuringer, 2002). The relative frequency of a specific sequence was defined as the number of times it had occurred since the beginning of the session (absolute frequency) divided by the total occurrences of all 16 sequences within the session. The relative frequencies at the start of each session were taken from the end of the preceding session. Whenever a reinforcer was delivered, the frequency of each of the 16 sequences was multiplied by a weighting coefficient of 0.95, thus generating an exponential decrease in the contribution of past sequences. The next reinforcer was delivered, then, when the weighted relative frequency of the current sequence was less than or equal to the threshold value; otherwise, the BO occurred. If, for example, the threshold value was set at 0.08, a reinforcer was provided only if the weighted relative frequency of the sequence was less than or equal to 8%; but if the threshold value was 0.80, a reinforcer was provided only if the weighted relative frequency was less than or equal to 80%. Thus, threshold values

closer to 0 require high levels of variability, whereas values closer to 1 require low levels of variability.

To examine the control of the variation requirement upon choosing, the threshold criteria in the TLs were manipulated across conditions. There were two types of conditions. In the non-differential conditions (100%), the threshold values were identical in both TLs. In the differential conditions (50% and 10%), the threshold in one of the TLs was identical to that in the 100% conditions (hereafter called the LOW criterion) whilst the threshold in the other TL became more stringent (hereafter called the HIGH criterion). The value of the HIGH criterion was determined by multiplying the value of the LOW criterion by 0.5 (50% conditions) or by 0.1 (10% conditions). Non-differential and differential conditions were alternated across the experiment. Due to a time constraint, subjects T03 and T05 were not exposed to the final 100% condition and to the two 50% conditions, respectively.

Table 1 shows the order of the experimental conditions and the number of sessions per condition for individual subjects. For each subject, the value above and below represents the threshold criteria correlated with the left and right keys, respectively. For example, for subject T02 in the first 50% condition, IL responses to the left key initiated the TL with the LOW criterion and IL responses to the right key initiated the TL with the HIGH criterion.

In the 100% conditions, all pigeons were exposed to a LOW criterion in both terminal links: 0.80 for subjects T01 and T04 and 0.70 for subjects T02, T03 and T05. Those values were chosen because they tend to generate low levels of variability. If values that generate high levels of variability were chosen, it would be difficult to obtain lower levels in subsequent conditions, as shown by some studies (Hunziker et al., 1998; Stokes, 1999; Stokes and Balsam, 2001; Stokes and Harrison, 2002).

In the 50% conditions, the values of the HIGH \times LOW criteria were 0.40×0.80 or 0.35×0.70 whereas in the 10% conditions those values were 0.08×0.80 or 0.07×0.70 . During the 50% and 10% conditions, when stable choice was observed, the HIGH and LOW criteria were reversed across TLs. For Subject T03, because differential levels of variability were not obtained after 19 sessions with the 0.35×0.70 criteria (50% condition), the reversal was not conducted.

In the differential conditions, the LOW criterion tended to produce greater rate and percentage of reinforcers than the HIGH criterion, thus making it difficult to determine whether the greater number of choices for the LOW criterion was controlled by the variation requirement or by the reinforcement rate and/or percentage. In order to isolate the influence of the threshold criterion upon choosing, the rate and percentage of reinforcers were maintained approximately identical between the two TLs. This was done by gradually decreasing the reinforcer probability in the LOW alternative. Each condition initiated with the same reinforcer probability (1.0) in both TLs. If significant differences were observed in the rate and percentage of reinforcers between the two TLs, the reinforcer probability in the LOW alternative was decreased to 0.9. If the differences remained during five sessions, the reinforcer probability was further decreased to 0.8, and so on. The minimum value needed to generate similar rate and percentage of reinforcers across terminal links was of 0.6. This value was utilized in one of the two 10% conditions for pigeons T01, T03 and T05, and in both 10% conditions for pigeons T02 and T04. Sequences that met the variability contingency but not the probability-of-reinforcement contingency were followed by the BO.

Each experimental condition was in effect until stability in the proportion of choices for the TL with the LOW criterion (LOW choices/total choices) and in the rate and percentage of reinforcers was achieved. The proportion of LOW choices was considered to be stable if the proportion in each of the last five sessions differed by no more than 15% from the average proportion of all five sessions taken together. Reinforcement rates and percentages

were considered to be stable if they were similar between the TLs as determined by visual inspection.

3. Data analyses

All measures refer to the data obtained in the last five sessions of each condition. In the TLs, the measures used were (a) the reinforcement rate, (b) the percentage of reinforced sequences, (c) the U value, (d) the relative frequency of the number of switches per sequence, (e) the relative LOW U values, and (f) the relative LOW number of switches.

- (a) *Reinforcement rate*. It was calculated by dividing the number of reinforcers obtained in one TL by the time (in minutes) spent in that TL.
- (b) *Percentage of reinforced sequences*. This measure was calculated by dividing the number of reinforced sequences in one TL by the total number of sequences in that TL. The quotient was multiplied by 100.
- (c) *U value*. This measure represents an index of overall sequence variability and it is calculated according to the following equation (Miller and Frick, 1949):

$$U = \frac{-\sum\{pix[\log(pi)]/[\log(2)]\}}{[\log(n)/\log(2)]}$$

where p is the probability (relative frequency) of occurrence of sequence i , and n is the total number of all possible sequences, which was 16 in the present study. A U value equal to 1 indicates that each one of the 16 possible sequences was emitted equally often and a U value equal to 0 indicates that only one sequence was emitted. U values were obtained for each TL.

- (d) *Relative frequency of the number of switches per sequence*. It was obtained by dividing the number of sequences with no switches in one TL by the total number of emitted sequences in that terminal link, and by multiplying the quotient by 100. The same calculation was done for sequences with 1, 2 and 3 switches.
- (e) *Relative LOW U values*. It was obtained by dividing the U value in the TL correlated to the left initial link (100% conditions) or in the LOW TL (50% and 10% conditions) by the sum of the U values in both TLs.
- (f) *Relative LOW number of switches*. In order to obtain this measure, the number of sequences with no switches in the LOW alternative (or in the alternative correlated to the left initial link in the case of the 100% condition) was divided by the total number of sequences with no switches in both TLs. The same calculation of performed for sequences with 1, 2 and 3 switches.

In the ILs, the main measures were (a) the percentage of sessions with greater LOW- and HIGH-criterion choices and (b) the relative choices for the LOW criterion.

- (a) *Percentage of LOW- and HIGH-choice sessions*. This measure indicates the percentage of sessions, in each condition, in which relative choices differed from 0.5. For example, suppose that relative choices in the five stability sessions of each of the two 50% conditions were 0.6, 0.7, 0.5, 0.4, 0.3, 0.5, 0.6, 0.5, 0.5, and 0.7. In this example, the relative choices were lower than 0.5 in two sessions (thus indicating preference for the HIGH TL in 20% of the sessions), whereas values above 0.5 were obtained in four sessions (thus indicating preference for the LOW TL in 40% of the sessions). Relative choices equal to 0.5 were not included in the analysis.
- (b) *Relative LOW choices*. This measure shows the relative distribution of responses to the keys in the ILs. In the 100% condition,

Table 1
Order of the experimental conditions and number of sessions (in parenthesis) in each condition for all subjects.

Subjects	IL keys	Experimental conditions							
		100%	50%	50%	100%	10%	10%	100%	
T01	Left	0.80	0.40	0.80	0.80	0.80	0.08	0.80	
	Right	0.80 (11)	0.80 (18)	0.40 (17)	0.80 (22)	0.08 (22)	0.80 (27)	0.80 (10)	
T02	Left	0.70	0.70	0.35	0.70	0.70	0.07	0.70	
	Right	0.70 (27)	0.35 (24)	0.70 (35)	0.70 (15)	0.07 (36)	0.70 (28)	0.70 (15)	
T03	Left	0.70	0.35		0.70	0.70	0.07		
	Right	0.70 (22)	0.70 (19)		0.70 (63)	0.07 (40)	0.70 (14)		
T04	Left	0.80	0.40	0.80	0.80	0.08	0.80	0.80	
	Right	0.80 (44)	0.80 (27)	0.40 (37)	0.80 (15)	0.80 (30)	0.08 (13)	0.80 (30)	
T05	Left	0.70				0.70	0.07	0.70	
	Right	0.70 (61)				0.07 (35)	0.70 (33)	0.70 (35)	

Note: The bold font indicates the LOW criterion; IL, initial link.

in which the threshold values were equal in both TLs, the relative choice was calculated dividing the number of responses to the left key by the total number of responses to the left and right keys. In the 50% and 10% conditions, in which the threshold values differed across TLs, the relative choice was calculated dividing the number of responses to the key correlated with the LOW criterion by the total number of responses to both keys. Relative choices equal to 0.5 indicate an equitative distribution of responses between the IL keys. Relative choices above or below 0.5 indicate more frequent responding on the IL key correlated with the LOW and HIGH criteria, respectively.

4. Results

4.1. Terminal links

The left panels of Fig. 2 presents the rate of reinforcers (in minutes) and the right panels presents the percentage of reinforced sequences, for each subject, in the last five sessions of each condition. It can be seen that in all conditions, and for all pigeons, those measures were similar between TLs, as it would be expected from the manipulations in the probability of reinforcers, although some exceptions occurred (e.g., see the last 100% condition of pigeons T02, T03 and T04 in the right panels). In general, the values of both measures were lower in the 10% condition than in the 50% and 100% ones.

Fig. 3 shows the mean *U* values in each condition. Individual data are presented in the top-five panels, and the mean data are presented in the bottom panel. The *U* values in both TLs were similar in the 100% and 50% conditions (excepting in the 50% condition of Pigeon T02). In the 10% condition, however, the *U* values tended to be greater in the HIGH-criterion TL than in the LOW-criterion TL. Also, the greatest *U* values were observed in the 10% condition. In the 50% condition, the *U* values were either similar to (for pigeons T01 and T04) or greater than (for pigeons T02 and T03) those in the 100% condition. We ran a repeated measures analysis of variance (ANOVA) having condition and TL-criteria as within-subject factors (pigeon T05 was excluded from this analysis because it was not exposed to the 50% condition). condition yielded a significant effect, $F(2, 6) = 15.99, p = .004, p\eta^2 = .84$, as well as TL-criterion, $F(1, 3) = 14.44, p = .032, p\eta^2 = .83$. These two factors also significantly interacted, $F(2, 6) = 11.03, p = .010, p\eta^2 = .79$. Follow-up repeated contrasts (i.e., comparing each condition with the previous one) indicated that the 100%

and 50% did not significantly differ from each other, $F(1, 3) = 2.51, p = .211, p\eta^2 = .46$, but the difference between conditions 50% and 10% was significant, $F(1, 3) = 78.54, p = .003, p\eta^2 = .96$. In addition, the effect of TL variability criteria was not different between 100% and 50% conditions, $F < 1, p = .930, p\eta^2 = .00$. However, the

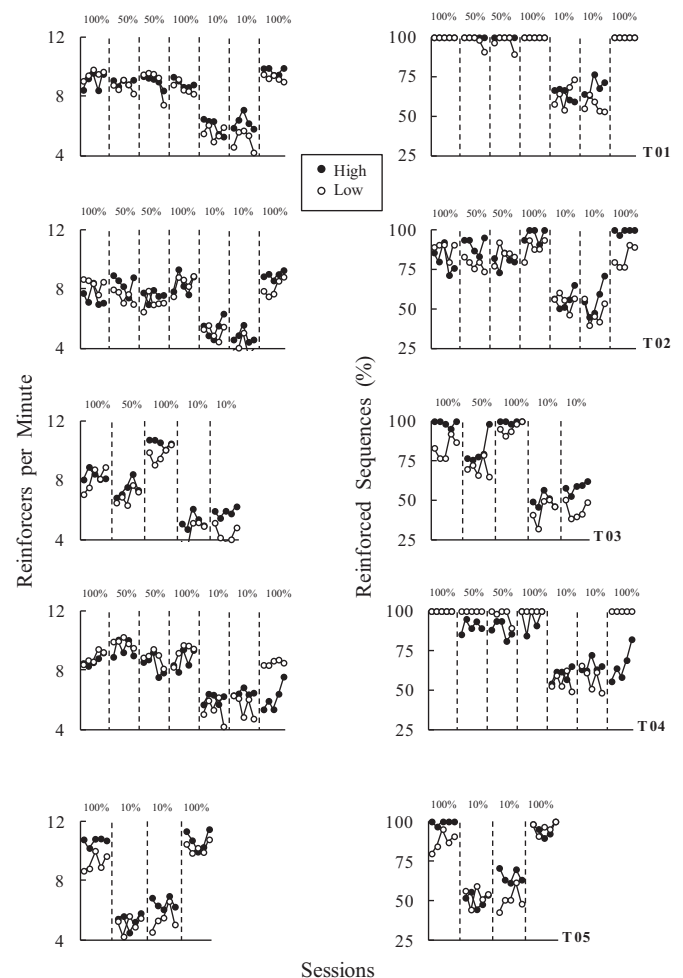


Fig. 2. Reinforcers per minute (left panels) and percentage of reinforced sequences (right panels) in the last five sessions of each condition for all pigeons.

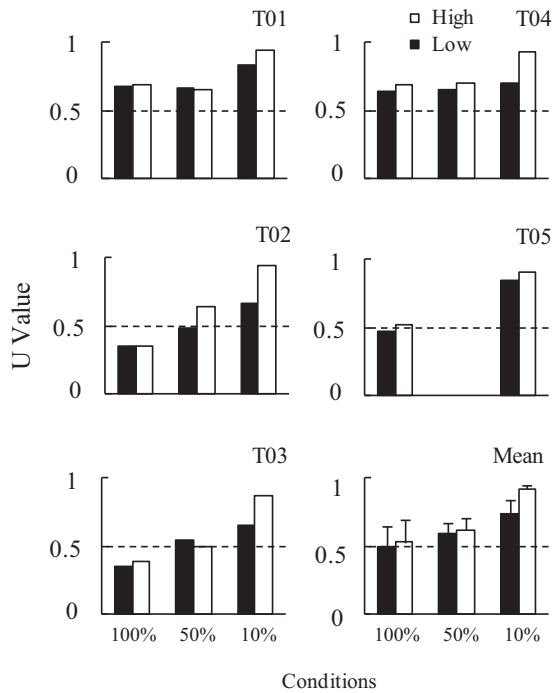


Fig. 3. *U* values in each condition for all pigeons. The bottom panel shows mean data (error bars correspond to one standard deviation).

LOW-criterion and HIGH-criterion produced differential levels of variability in the 10% condition, $F(1, 3) = 28.48, p = .013, \eta^2 = .95$.

The relative frequency of the number of switches per sequence across the TLs of each condition is indicated in Fig. 4. The data were averaged across subjects. The binomial distribution predicted by

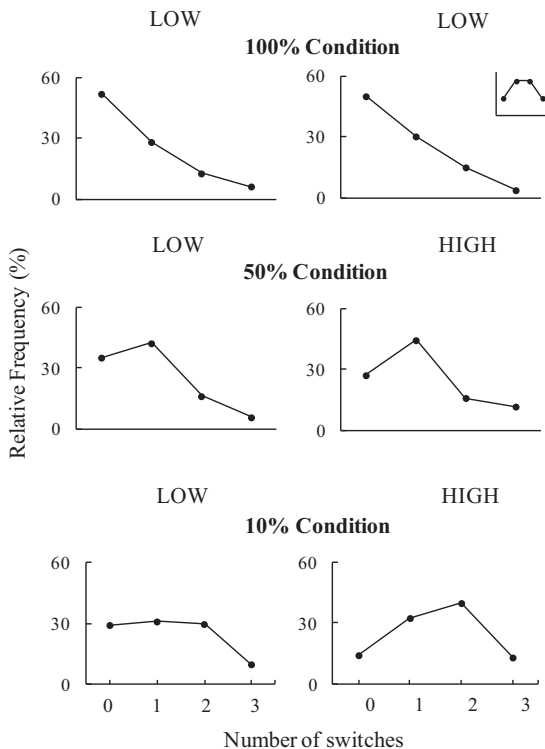


Fig. 4. Mean relative frequency of the number of switches per sequence in each condition. The binomial distribution predicted by random responding is also presented in the top-right panel. Data were averaged across subjects.

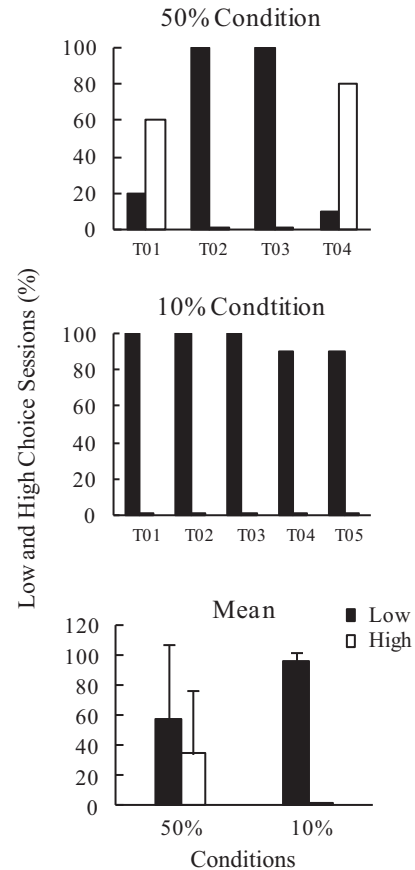


Fig. 5. Percentage of LOW- and HIGH-choice sessions for each pigeon in the 50% and 10% conditions. The bottom panel shows mean data (error bars correspond to one standard deviation).

random responding, that is, when the 16 possible sequences occur equally often, is also presented in the top-right of the figure. In the 100% condition, in which the LOW criterion was in effect in both TLs, sequences with no switches were the most frequent ones, followed by those with 1, 2 and 3 switches, in that order. In the 50% condition, one-switch sequences occurred more often than sequences with no switches, and both occurred more frequently than sequences with 2 and 3 switches in spite of the variation criterion. In the 10% condition, the distribution was flatter with the LOW criterion, although three-switch sequences remained the least frequent ones, but with the HIGH criterion, the distribution approached random performance (one- and two-switches sequences became the most frequent ones).

4.2. Initial links

An analysis of choice is shown in Fig. 5. The top-two panels show the percentage of LOW- and HIGH-choice sessions for each pigeon in the 50% and 10% conditions, and the bottom panel presents the mean data. During the 50% condition the data were asymmetric: HIGH-choice sessions predominated for two subjects (T01 and T04) whereas the opposite was observed for the remaining subjects. In the 10% condition, only LOW-choice sessions occurred for subjects T01, T02 and T03, and for subjects T04 and T05, 90% of the sessions were LOW-choice sessions. The mean data shows that LOW-choice sessions were more frequent in the differential conditions, especially in the 10% condition, than in 100% one. Again, we ran an ANOVA having condition and TL as within-subject factors (as before, data from T05 did not enter the analysis). The only effect that approached significance was of Condition, $F(1, 3) = 6.55,$

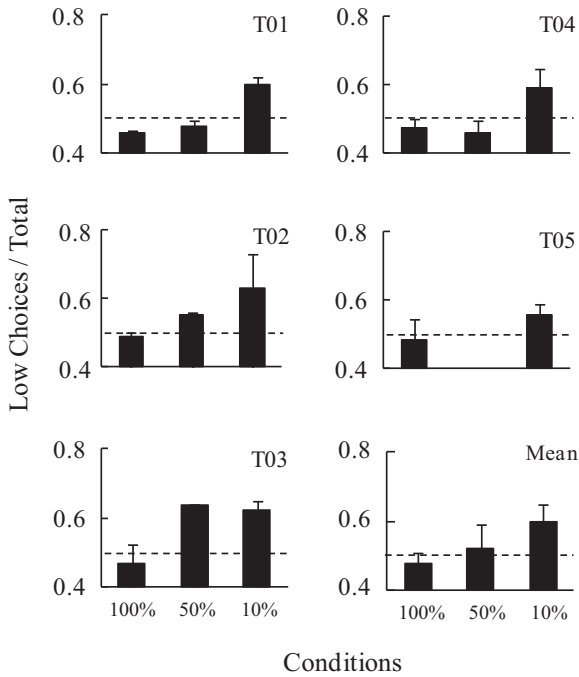


Fig. 6. Relative LOW choices as a function of each condition for all subjects. The bottom-right panel shows mean data (error bars correspond one standard deviation).

$p = .083$, $p\eta^2 = .67$. We also ran *t*-tests comparing LOW-choices and HIGH-choices in each condition. LOW- and HIGH-choices did not differ in the 50% condition, $t(3) = .5$, $p = .653$, but in the 10% condition, LOW-choices were greater than HIGH-choices, $t(4) = 39.19$, $p < .001$.

Fig. 6 shows the relative LOW choices in each condition for each subject. The first 100% condition of pigeon T01 was excluded from the analysis because choice values differed greatly from those obtained in the second and third 100% conditions. Relative LOW choices tended to change as a direct function of the degree of variability required in the HIGH terminal link: the higher the variability required (10% condition), the more the subjects preferred the terminal link associate with the LOW variability requirement. Relative LOW choices in the 50% condition tended to be similar either to those in the 100% conditions or those in the 10% condition. These three conditions were compared with a repeated measures analysis of variance (ANOVA), which yielded a significant effect, $F(2, 6) = 6.57$, $p = .031$, $p\eta = .69$. The linear trend contrast was also found to be significant, $F(1, 3) = 79.15$, $p = .003$, $p\eta = .96$, corroborating the direct relation between the degree of variability in the HIGH link and choice for the LOW link. Pairwise comparisons indicated that the 10% condition significantly differed from baseline ($p = .003$), whereas the 50% condition did not significantly differ either from the 10% ($p = .109$) or 100% condition ($p = .403$).

Relative LOW choices as a function of the relative LOW *U* values are presented, for each subject, in the left panels of Fig. 7. It is also shown, in the right panels, the relative LOW choices as a function of the relative LOW number of switches per sequence. For each switch number, the data are averaged across subjects. Solid lines are fitted least-squares regression lines. The equation of the fitted line ($y = ax + b$, where *a* is the slope and *b* is the intercept) is presented in each graph. Each data point corresponds to one condition. Pigeon T05 was not included in the left panels because it had only two data points, what may compromise the predictability of its function. The left panels show that, with the exception of Pigeon T03, relative choices for the LOW TL decreased with increases in the relative *U* values in that TL. The slope values indicate that changes in

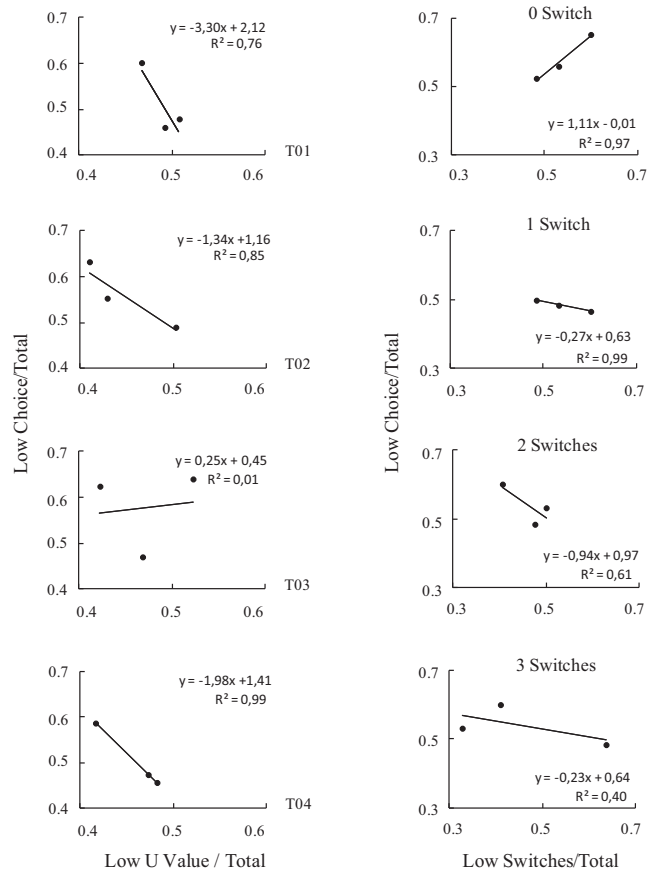


Fig. 7. Relative LOW choices as a function of the relative LOW *U* values (left panels) for each subject. Also, the relative LOW choices as a function of the relative LOW switches (right panels) for each switch number. See text for details.

the relative LOW choices were greater than changes in the relative LOW *U* values. The R^2 values ranged from 0.85 to 0.99, suggesting that changes in preference may be accounted for by the relative probability of LOW versus HIGH *U* values in the terminal links. For Pigeon T03, choice was not affected by the relative *U* value.

The right panels of Fig. 7 indicate that choice was influenced also by the number of switches per sequence. As the relative number of no-switch sequences increased in the LOW alternative, choice for that alternative increased as well ($R^2 = 0.97$). However, increases in the relative number of 1-switch and 2-switch sequences in the LOW alternative were followed by decreases in the relative LOW choices (R^2 equal to 1.0 and 0.61, respectively). And, when the relative number of 3-switch sequences increased in the LOW alternative, the relative LOW choices remained close to indifference between the LOW and HIGH alternatives ($R^2 = 0.4$). For the no-switch and 2-switch analysis, the slope values indicate that changes in both measures tended to be proportional whereas for the 1-switch and 3-switch sequences, changes in the relative LOW choices tended to be proportionally lower than changes in the relative number of switches in the LOW alternative. The decrease in the R^2 values with increases in the number of switches suggests that relative choices for the LOW variation criterion was no longer predicted by within-sequence switches when that criterion produce highly costly sequences.

5. Discussion

The programming of differing variation requirements in the TLs of a concurrent-chains schedule generated differing degrees

of behavioral variation. That is, consistently with other studies (e.g., Abreu-Rodrigues et al., 2005, 2007; Machado, 1989; Page and Neuringer, 1985), variation in the emission of four-response sequences tended to be greater with the more stringent variation requirement than with the less stringent one, mainly in the 10% condition. Also, and mostly important in the present study, when facing those two TLs, there was a tendency for pigeons to choose more frequently the one with the least stringent variation requirement. This result expands those reported by Abreu-Rodrigues and collaborators (2005, 2007). In their studies, preference for an alternative in which variation was not required increased as a direct function of the variation criterion in the other alternative. However, because the percentage of reinforcers changed inversely with the variation criterion, it was not clear whether choices were controlled by the variation requirement or the percentage of reinforcers. This confounding effect was eliminated in the present study as long as the rate and percentage of reinforcers were similar across TLs.

5.1. *U* values

That pigeons tended to show higher levels of behavioral variation under the more stringent than the less stringent threshold criterion is in accord with the results obtained with other species, such as rats (e.g., Grunow and Neuringer, 2002; Wagner and Neuringer, 2006) and humans (e.g., Abreu-Rodrigues et al., 2007; Hunziker et al., 1998), and with differing variation criteria, such as the lag (e.g., Page and Neuringer, 1985; Stokes, 1999) and the percentile (e.g., Machado, 1989) ones.

Non-differentiated *U* values across TLs occurred more often under the 50% than the 10% conditions, a result that may be explained on basis of the lower discriminability of the threshold-criterion values in the 50% conditions. This suggestion is supported by the studies of Grunow and Neuringer (2002) and Souza and Abreu-Rodrigues (2010). Grunow and Neuringer reported lower *U* values with a threshold value equal to 0.074 than to 0.055 or 0.037, but similar *U* values with these last two criteria. In line with this finding, Souza and Abreu-Rodrigues observed in an arbitrary matching-to-sample procedure in which vary and repeat contingencies served as the sample to subsequent choices, that reductions in the variation requirements were followed by (1) decreases in the differences between the *U* values engendered by both contingencies and (2) increases in the number of inaccurate matching responses. Thus, the discriminability of vary and repeat contingencies was influenced by the degree of discrepancy between the obtained levels of behavioral variability. Thus, both studies, together with the present one, seems to indicate that the discriminative control exerted by differing vary contingencies (or by vary versus repeat contingencies) may be jeopardized by the similarity of the behavior controlled by both contingencies.

In the 10% conditions, however, even though the magnitude of the discrepancy between the threshold values may be considered high, at least in comparison with the 50% conditions, the *U* values did not differ greatly for all subjects (e.g., T01 and T05), what may be attributed to the experimental history with variation. That is, small differences between the *U* values of the two TLs, mostly observed in the second exposure to the 10% condition, occurred because the *U* value in the TL in which the criterion changed from high to low (e.g., from 0.08 to 0.80) remained high while the *U* value in the other TL in which an opposite change happened (e.g., from 0.80 to 0.08), increased. These effects were likely to have occurred because the maintenance of the high *U* values produced by the 0.08 criterion were still reinforced under the 0.80 criterion, but the maintenance of the low *U* values generated by the 0.80 criterion were not effective in producing reinforcers under the more stringent criterion. The maintenance of high *U* values in despite of the lowering of the variation requirement was also pointed out in other

studies (Hunziker et al., 1998; Stokes, 1999; Stokes and Balsam, 2001; Stokes and Harrison, 2002; Yamada and Hunziker, 2008). In Stokes' study, for example, college students were exposed to an increasing (from 0 to 25) or decreasing (from 25 to 0) order of lag values. The results showed that under the Lag 0 criterion, sequence variation was greater with the decreasing than the increasing order.

5.2. Number of switches per sequence

Manipulations in the variability requirement also affected the number of within-sequence switches such that as the variation criterion became more stringent, as greater the number of switches per sequence. When the LOW criterion was in effect in both TLs, the *U* values were low, and half of the emitted sequences contained no switches. That is, the animals' behavior was highly effective in obtaining reinforcers (see Fig. 2) by repeatedly emitting low-cost sequences (four left-key responses or four right-key responses). Such sequence stereotypy, however, was not as effective when the criterion became more rigorous. Under the differentiated conditions, sequence variation increased, as shown by the *U* values, and such variation was characterized by the predominance of 1-switch sequences in the 50% condition and 2-switch sequences in the 10% condition. These results suggest efficient responding as long as variation and switching were just enough to meet the contingencies. Similar results were obtained by Abreu-Rodrigues et al. (2005).

5.3. Choice

The majority of the differential conditions across pigeons showed a predominance of choices for the more lenient threshold criterion. Because rate and percentage of reinforcers were comparable across TLs, and no other difference was evident besides that in the threshold criteria, it can be said that choice was controlled by the variation requirement. This result, together with those reported by Abreu-Rodrigues and collaborators (2005, 2007), indicates that when there are two behavioral alternatives for obtaining reinforcers, humans and nonhumans tend to choose the one that requires less variation. A question that follows is related to which aspect of the variability contingency covaried with choice. In the present study, two aspects were in place, sequence variation (*U* values) and switching (see Fig. 7), given that choice for the LOW-criterion alternative increased with the *U* value and the number of switches in the HIGH-criterion alternative.

Preference for less demanding contingencies may be a function of the cost involved in emitting varied behaviors. As pointed by some authors (Barba and Hunziker, 2002; Machado, 1997), the emission of sequences comprehends two types of responses: operandum responses and switching responses between operandum. For example, the LLLL sequence, with all responses on the same key, contains four operandum responses and no switching responses whereas the LRLR sequence, with responses distributed between two keys, contains also four operandum responses but three switching responses. Hence, to obtain reinforcers, the organism makes more effort and dispends more time in emitting the second (higher cost) than the first (lower) sequence. If high levels of variation are required, all possible sequences tend to be emitted with similar probability, therefore, sequences with few, intermediate or several switches occur. Conversely, if low levels of variation are demanded, sequences with few switches are sufficient to produce reinforcers, and because they involve lower cost than sequences with many switches, they are more likely (cf. Abreu-Rodrigues et al., 2005). It follows that, when required to choose between high and low vary contingencies, the organisms may tend to choose the least costly one, that is, the one that requires less variation. Three pigeons of the present study presented results that support the possibility of control by the number of switches within a sequence. As indicated

by Fig. 4, sequences with three switches were more frequent in the HIGH-criterion TL during the 10% condition than during the 100% condition. Considering that LOW choices, as compared to HIGH choices occurred less often in the 10% than in the 100% condition, it may be suggested that control by the variation criterion was mediated by response cost. Thus, organisms may prefer not only to vary less, but also to vary with less cost.

The suggestion of control by the cost of responding is supported by Lôbo's study (2012). College students had to choose between two TLs. In Experiment 1, identical lag criteria were in effect in both TLs, but in one TL only sequences with two (VAR 2) switches were reinforced, whereas in the other TL only sequences with five (VAR 5) switches were required. Choices for the low-cost TL (VAR 2) were more frequent than for the high-cost TL (VAR 5). In Experiment 2, choice was between one vary (VAR 2 or VAR 5) and one repeat (REP 2 or REP 5) contingency. Choices for the REP alternative increased as a direct function of the number of switches in the VAR alternative. Taken together, these results show that choices for low-cost responding prevailed over choices for high-cost responding, thus supporting the suggestion that response cost may interact with the level of response variation in determining choice.

Two additional aspects may be mentioned. First, although preference for the more lenient criterion was observed in the differentiated conditions, the magnitude of that preference was not pronounced. That is, the proportion of LOW-criterion choices was no greater than 0.64 in the 50% condition, and 0.70 in the 10% condition. The attempt to keep the percentage of reinforcers similar across TLs may be responsible for such effect. That is, decreasing the probability of reinforcers in the TL with the LOW criterion may have attenuated the reinforcing value of that criterion. Second, indifference between alternatives was observed in the 50% conditions of Pigeon T01. In those cases, the threshold criteria (0.08 and 0.80) failed in producing differentiated degrees of sequence variation. Hence, not only the rate and percentage of reinforcers were similar in the TLs, but also the *U* values; as it would be expected, then, no preference was obtained. Comparable results were reported by Abreu-Rodrigues et al. (2005).

In conclusion, the present study showed that more lenient variation requirements are preferred over more stringent ones. However, given that less variation may not favor the learning of more complex behaviors (e.g., problem solving, creativity), further studies should investigate how to promote choice for more demanding contexts.

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