

*PREFERENCE FOR SIMPLE INTERVAL SCHEDULES OF
REINFORCEMENT IN CONCURRENT CHAINS:
EFFECTS OF SEGMENTATION RATIO*

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A concurrent-chains procedure was used to examine pigeons' preferences between segmented and unsegmented terminal-link schedules of reinforcement. During the initial link, a pair of independent, concurrent variable-interval 60-s schedules was in effect. In the terminal link, reinforcement was provided by a chain fixed-interval fixed-interval schedule on one key and by a simple fixed-interval schedule with an equal interreinforcement interval in the other. The relative duration between the first and second components (segmentation ratio) in the terminal-link chained schedule was systematically varied while the terminal-link duration was kept constant at either 15 s or 30 s in two sets of conditions. With few exceptions, the simple schedule was preferred to the chained schedule. Furthermore, this preference was inversely related to the size of the segmentation ratio in the segmented schedule. When the segmentation ratio was smaller than 1:1, preference was more extreme for a 30-s condition than for a 15-s condition. However, preference decreased more rapidly in conditions with the longer terminal-link duration when the ratio increased. Taken together, these results were consistent with previous findings concerning the effect of the terminal-link duration on choice between segmented and unsegmented schedules. In addition, the data suggested that segmentation ratio in a segmented schedule constitutes another potent factor influencing preference for the unsegmented schedule.

Key words: preference, segmentation ratio, interreinforcement interval, segmented schedules, psychological distance, concurrent chains, pigeons

The concurrent-chains procedure (Autor, 1960, 1969; Herrnstein, 1964) is commonly used to study pigeons' choice between two schedules of reinforcement. Such a procedure typically includes two phases, the initial link (choice phase) and the terminal link (outcome phase). The initial link consists of two illuminated response keys, each correlated with an independent variable-interval (VI) schedule. Pecking on either key occasionally produces a specific schedule of reinforcement correlated with a stimulus change on that key while the other key becomes dark and inoperative. The terminal link is now in effect. Completion of the schedule requirements in the terminal link produces food and reinstatement of the initial link. The relative allocation of responses (or times) on the two keys during the initial link (the choice proportion) is taken as a measure of preference for one of the two mutually exclusive terminal-link schedules.

The effect on choice of segmenting a simple interval schedule also has been investigated using the concurrent-chains procedure (e.g., Duncan & Fantino, 1972). A terminal-link schedule is said to be segmented if it is divided into two or more component schedules by certain events such as a stimulus change, a response requirement, or both (Fantino, 1969b). A good example is a chained schedule in which two component schedules (C1 and C2), each correlated with a different stimulus (S1 and S2, respectively), have to be completed in sequence before the primary reinforcer can be produced. Fantino (1969b) suggested that segmenting a schedule increases the number of stages to be traversed prior to the presentation of the reinforcer, and this effectively extends the "psychological distance" to reward. A direct implication of the psychological distance hypothesis is that a segmented terminal-link schedule will be less preferred than its unsegmented counterpart. In Duncan and Fantino's (1972) first experiment, pigeons were presented with a simple fixed-interval (FI) 2X-s schedule and a chain FI X-s FI X-s schedule in the terminal link. As predicted, subjects showed a strong preference for the simple schedule over the segmented one when both

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terminal-link schedules were the same duration. In addition, such preference increased as the duration of the terminal link was varied from 10 s to 20 s and to 30 s. The simple schedule was almost exclusively preferred when the terminal link was 30 s long.

Duncan and Fantino's (1972) findings were recently replicated by Leung and Winton (1985). In certain conditions, Leung and Winton also compared a simple FI 2X-s schedule and a chain FI X-s FI X-s schedule but the interval between primary reinforcers was either 15 s or 60 s. Pigeons invariably favored the simple schedule over the chain and did so much more in conditions with the longer terminal link. The generality of Duncan and Fantino's findings also extends to VI schedules in the terminal link (Leung & Winton, 1985), to chain versus tandem schedules (Fantino, 1983), and to response-independent schedules of reinforcement (Leung & Winton, 1986; Wallace, 1973). In short, the negative effect on choice produced by segmentation seems to be a rather robust phenomenon in the time-based terminal-link schedules of reinforcement.

In the past, experiments conducted on segmentation and choice have invariably divided the terminal-link schedule into two equal halves so that C1 always had the same duration as C2. However, it is important to know whether uneven segmentation of schedules would have similar adverse effects on choice. Such information will be useful for the understanding of choice in the concurrent-chains procedure in general and the segmentation phenomenon in particular. A recent attempt was made to investigate unevenly segmented schedules (Leung & Winton, 1986). Pigeons were presented with a chain FI fixed-time (FT) and its corresponding tandem schedule in the terminal link of the concurrent chains. Over five conditions, the C1 duration was varied (5 s, 10 s, 15 s, 20 s, and 30 s) while the C2 duration was kept constant at 5 s. This manipulation produced uneven segmentation because most of the segmented schedules had C1 durations longer than C2 durations.

Previous research on segmentation (e.g., Duncan & Fantino, 1972; Leung & Winton, 1985) has consistently found that choice was a positive function of the terminal-link duration. Thus, because increasing the duration of C1 also increased the duration of the whole

terminal link, subjects in the Leung and Winton (1986) experiment were expected to show increasing preference for the less segmented tandem schedule as the C1 duration became larger. Furthermore, extreme preference was expected when the terminal-link duration was 35 s because Duncan and Fantino (1972) recorded choice proportions of .90 or above using a slightly shorter terminal link (30 s). However, these predictions were not borne out in the results of Leung and Winton (1986). Although in most cases pigeons did favor the tandem schedule over the chain, choice proportions were not as high as expected (range, .45 to .62), and they varied in a seemingly inverse fashion with the duration of C1 and thus the length of the terminal link. These unusual results obtained by Leung and Winton suggest that the point of segmentation within the terminal link must have played a substantial part in affecting choice. This variable was represented in terms of the relative duration between C1 and C2 and was labeled as the segmentation ratio. Unfortunately, the exact influence of segmentation ratio on preference for segmented over less segmented schedules could not be easily deduced from Leung and Winton's data. By manipulating the C1 duration while keeping the C2 duration constant across conditions, Leung and Winton had simultaneously changed the duration of the terminal link as well as the segmentation ratio. Consequently, an unequivocal interpretation of the findings concerning the effects of terminal-link duration and segmentation ratio was impossible. Nevertheless, the findings of Leung and Winton demonstrate how preference for the less segmented schedule can be affected by the segmentation ratio.

The present experiment was another attempt to explore the effect of the segmentation ratio in a segmented-interval schedule and to further replicate previous findings concerning the effect of the duration of the terminal link. As in previous studies, the concurrent-chains choice procedure was used, and pigeons were presented with either a chain FI FI or a simple FI of the same total duration in the terminal link. To allow the effect of the segmentation ratio to be examined independently, the segmentation ratio in the chain was varied for a set of conditions while the terminal-link duration was held constant. Furthermore, to assess the effect of the terminal-link duration,

two sets of conditions were conducted, each with a different terminal link.

METHOD

Subjects

Four homing pigeons of racing stock, designated P14, P27, P34, and P37, were maintained at 80% (± 10 g) of their free-feeding body weights. They had had previous exposure to concurrent schedules using both side keys of the experimental chamber.

Apparatus

The experimental chamber was a standard three-key pigeon chamber (Gerbrands G7463). The enclosure was made of sound-attenuating material, with an exhaust fan that helped mask external noise. Throughout the experiment, only the two side keys were operative. The center key was covered with black insulation tape. Each side key could be transilluminated with 1.3-W lights of various colors. A force of 0.15 N operated the microswitch behind each key. Auditory feedback for pecking was a 30-ms 1-kHz tone produced by a sine-wave generator. Reinforcement consisted of 3-s access to wheat in a raised, illuminated hopper with the houselight and keylights off. Experimental events were controlled and recorded by electromechanical and solid state equipment.

Procedure

All pigeons were immediately given concurrent-chains training. During the initial link, the two side keys were illuminated white and responding on either key occasionally produced a change in color on that key and the respective terminal-link schedule. Two independent VI 60-s schedules and a changeover delay (COD) of 1.5 s (Herrnstein, 1961) always operated during the initial link. That is, entry into a terminal link could not occur sooner than 1.5 s after a changeover from one key to the other. Baseline training was conducted first with identical tandem FI 7.5-s FI 7.5-s schedules in the terminal link. In the training conditions that followed, the two terminal-link schedules were always a chain FI X s FI Y s and a simple FI (X + Y) s. The terminal-link duration (X + Y) and the segmentation ratio (X:Y) of the chained schedule are shown for

each bird in Table 1, which also presents the particular order of exposure, the position of the chain key, and the number of sessions in each condition. The duration of the terminal link was 15 s in Conditions 1 through 5 and 30 s in Conditions 6 through 10. (Note that the order of training was different with different birds.) For the 15-s terminal link, the durations (in seconds) of C1 and C2, respectively, were 1, 14; 5, 10; 7.5, 7.5; 10, 5; 14, 1; and for the 30-s terminal link they were 2, 28; 10, 20; 15, 15; 20, 10; 28, 2. Thus the same segmentation ratios of 1:14, 1:2, 1:1, 2:1, and 14:1 were used for both durations.

In baseline, the terminal-link stimulus for the left key was green and the right key was blue for 2 birds (P14 and P27) whereas these stimuli were reversed for the other 2 birds (P34 and P37). For the 15-s conditions, C1 and C2 of the chain were red and green for P14 and P27 or green and blue for P34 and P37, respectively. The simple schedule was correlated with a blue (P14 and P27) or a red (P34 and P37) stimulus. For the 30-s conditions, the sets of stimuli were interchanged between the two groups of birds.

The intervals for the VI schedules were generated from progressions that scheduled events after varying times but with a constant probability (Fleshler & Hoffman, 1962). Sessions were conducted 7 days per week. Each session was terminated after the delivery of 40 reinforcers; hence session time varied with the length of the terminal link. A new condition was introduced when the response rates in both links of the concurrent chains appeared stable by visual inspection and the mean choice proportion of the last five sessions did not differ by more than 5% from that of the previous five sessions.

RESULTS

In the following analysis, the reinforcement proportion refers to the ratio of the reinforcement rates obtained during the unsegmented terminal-link schedule (the simple FI) to the total rate on both terminal-link schedules. Similarly, the choice proportion during the initial link was calculated by dividing the initial-link response rate on the key correlated with the unsegmented terminal link by the total initial-link response rate on both keys. All data presented are averaged over the last five ses-

Table 1

For each subject, the training conditions including the order of the conditions and the inter-reinforcement interval (IRI) of the chained schedules in the terminal link. Also shown are the order of conditions, the position of the key upon which the chain was scheduled, and the number of sessions required for each condition. The IRI values are in seconds.

Con- dition	Terminal- link chain		P14			P27			P34			P37		
	IRI	Seg. ratio	Or- der	Chain key	No. of sess.	Or- der	Chain key	No. of sess.	Or- der	Chain key	No. of sess.	Or- der	Chain key	No. of sess.
1	15	1:14	1	L	26	5	R	35	10	L	22	6	R	29
2	15	1:2	2	L	32	4	R	34	9	L	23	7	R	30
3	15	1:1	3	L	30	3	R	30	8	L	25	8	R	25
4	15	2:1	4	L	25	2	R	30	7	L	25	9	R	26
5	15	14:1	5	L	24	1	R	32	6	L	26	10	R	41
6	30	1:14	6	R	24	10	L	42	1	R	28	5	L	35
7	30	1:2	7	R	22	9	L	35	2	R	27	4	L	30
8	30	1:1	8	R	28	8	L	37	3	R	30	3	L	31
9	30	2:1	9	R	26	7	L	32	4	R	24	2	L	28
10	30	14:1	10	R	25	6	L	35	5	R	25	1	L	31

sions of a condition. During baseline, the choice and reinforcement proportions (with respect to the left key) were, respectively, .47 and .51 for P14, .48 and .50 for P27, .52 and .48 for P34, and .51 and .53 for P37.

The initial-link response rates correlated with the simple and chained terminal-link schedules can be found in the Appendix. A summary of the choice and reinforcement data for each bird is presented in Figure 1; the dependent variables are plotted as a function of the logarithm of the segmentation ratios for each terminal-link duration (15 s and 30 s). A logarithmic (rather than a linear) scale was employed on the x axis so that equal distance along this axis corresponds to equal ratios. From Figure 1, it can be seen that the reinforcement proportions were usually about .50, except in conditions with the longer (i.e., 30 s) terminal link and smaller segmentation ratios (e.g., 1:14) in which they tended to rise above .50. With few exceptions, the choice proportions were higher than .50, suggesting that the simple schedules were preferred to their equivalent chains.

Figure 1 also shows, for both terminal-link durations, that choice proportions were usually negatively related to the segmentation ratios. For the 30-s functions, preference was extreme (i.e., the choice proportion was about .90 or even higher) at the smallest segmentation ratios, and preference decreased sharply as the ratio became larger. In fact, when the segmentation ratio was increased to 14:1 and

the terminal link was 30 s (Condition 10), the relative responding of 3 of the 4 birds appeared slightly in favor of the chain (.41-.48). The exception was P34 whose choice proportion was .52, the same as during baseline. The same trend can be seen in the functions obtained with the 15-s terminal link, except that the slopes are lower. For most segmentation ratios used in this experiment, preference was stronger with the 30-s terminal link than with the 15-s one. But this difference was reduced with increasing segmentation ratio size, and appeared to reverse when the ratio was sufficiently large. Hence, the 15-s function had higher values than the 30-s one with large ratios such as 2:1 (for P37) and 14:1 (for all birds). Apparently, the two independent variables, segmentation ratio and terminal-link duration, interacted to determine the preference shown for the simple schedule.

Figure 2 shows the absolute response rates under the terminal-link schedules of both durations for each individual bird. Pigeons' performances under each component of the segmented schedule (the chain) were different in terms of the rate of responding. Response rates were lower in the first (C1) than in the second (C2) component of the terminal-link chain. The one exception was P34 who had similar rates in both components during Condition 10 due largely to a short pause occurring after an entry into the 2-s C2. The response rates in C2 sometimes exhibited a negative relationship with its duration. The response rates in

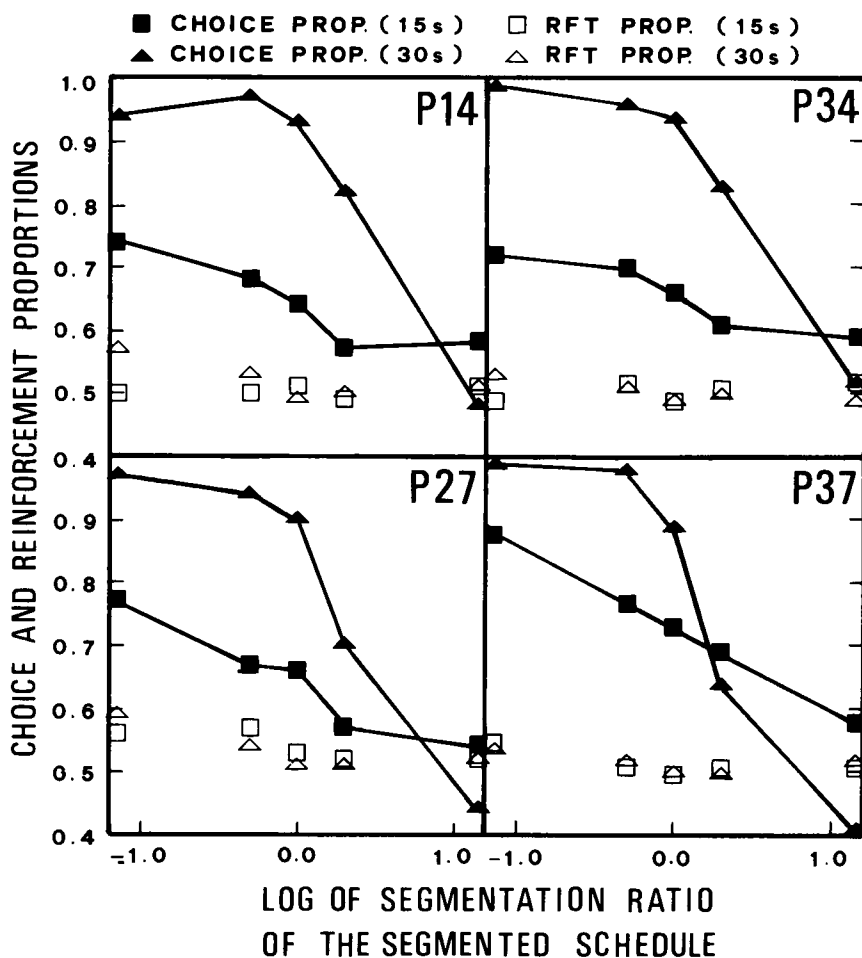


Fig. 1. For each subject, choice and reinforcement proportions for the unsegmented FI schedules as a function of the logarithm of the segmentation ratio (duration of the first segment, divided by that of the second segment) in the alternative, chained schedule for two terminal-link durations, 15 s and 30 s.

C1, however, did not show any clear-cut trend. The response rates under the simple schedule were usually intermediate between the rates in C1 and C2 of the chain. They varied unsystematically over conditions for a particular terminal-link duration. As expected, rates of responding under the shorter terminal link were usually higher than those under the longer one.

DISCUSSION

Previous research on schedule segmentation established that the duration of the terminal link influences choice between a simple schedule and its segmented counterpart. Specifically, preference was found to be positively related

to the length of the terminal link of the concurrent chains (Duncan & Fantino, 1972; Leung & Winton, 1985). The present experiment replicated this finding. With few exceptions, our results showed that the choice proportion obtained when the terminal link was 30 s was higher than that obtained when the terminal link was 15 s for a given segmentation ratio. In addition, the point of segmentation within the terminal-link interval was found to be a potent factor affecting choice. For a given terminal-link duration, preference was a negative function of the segmentation ratio. Choice proportions dropped to the vicinity of .50 (with 3 of the 4 subjects exhibiting a minor reversal) when ratios became relatively high (e.g., 14:1). Furthermore, these functions were steeper

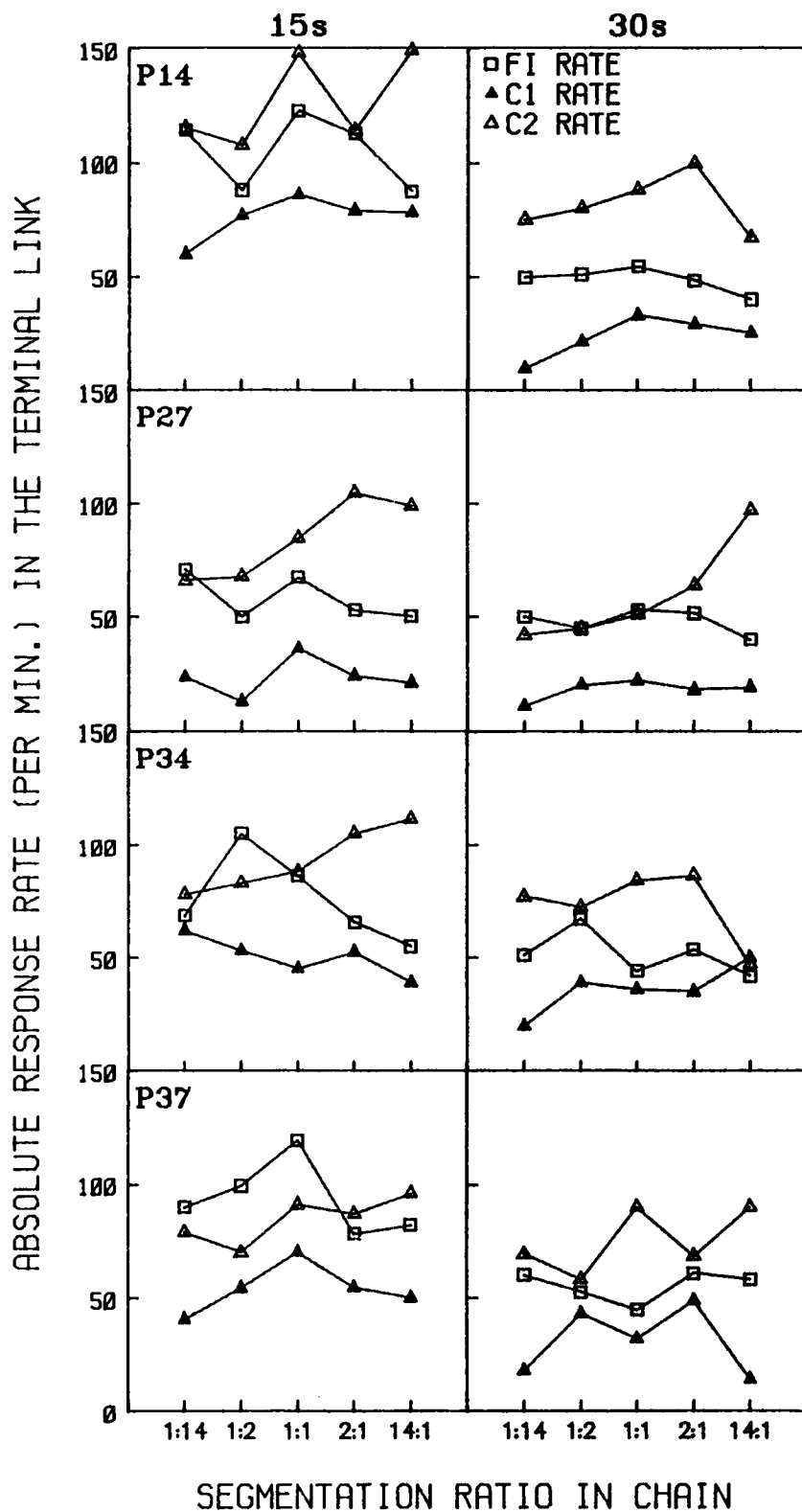


Fig. 2. The absolute rate of responding in each component of the terminal-link schedules as a function of the segmentation ratio for each subject. The rates for each of the two terminal-link durations (15 s and 30 s) are shown.

when the terminal link was 30 s than when it was 15 s.

The finding of interaction between the terminal-link duration and segmentation ratio helps to account for the results obtained in our earlier study (Leung & Winton, 1986), which also attempted to explore the effect of different segmentation ratios on schedule preference. In that experiment, we found choice proportions of unusually low magnitude that were negatively related to the overall duration of the terminal link. We suspected that such results were due to the particular procedure being used: By increasing the duration of C1 in the segmented schedule and keeping the duration of C2 constant, the terminal-link duration increased simultaneously with the segmentation ratio. Hence the longest terminal link (35 s) was directly correlated with the highest ratio (6:1), and the shortest terminal link (10 s) was correlated with the minimum ratio (1:1). According to the present results, low preference would be expected due both to the high ratio in the former case and the short terminal link in the latter. As a consequence, choice proportions of low magnitude were to be expected for all the intermediate conditions as well. The increasing segmentation ratio was probably responsible for the inverse function found between preference and the length of C1, which was directly proportional to the overall terminal-link duration.

One puzzling finding of the present study is the reversal (i.e., a chain preferred over a simple schedule) observed in 3 of the 4 subjects in the condition with the 30-s terminal link and a 14:1 segmentation ratio. A similar observation was made in our previous experiment (Leung & Winton, 1986). In that situation, preference for the less segmented terminal link was also exhibited in 2 of the 4 subjects when the terminal link was 35 s long and the ratio was 6:1. This finding of preference for a segmented over a less segmented schedule, if substantiated, has important implications for segmentation research because it is inconsistent with the psychological distance hypothesis proposed by Fantino (1969b) to explain the adverse effects of segmentation on choice. Based on these data, it is tempting to suggest that a segmented schedule is preferred to a simple one when given the right combination of terminal-link duration and segmentation ratio. Unfortunately, available data were

far from clear because only a minimal preference shift was recorded (range, .41 to .48) in the present experiment and the previous one, and the effect was not consistently observed in all subjects. Perhaps the reversal was caused by other extraneous variables. Under the circumstances that large segmentation ratios reduce preference toward indifference, initial-link responding could be easily affected by factors such as key bias. Hence, until the reversal effect can be consistently and reliably observed, any definite conclusion must be deemed premature.

A number of quantitative models have been developed to account for choice in concurrent chains (e.g., Davison & Temple, 1973; Fantino, 1969a, 1969b; Fantino & Davison, 1983; Herrnstein, 1964; Squires & Fantino, 1971; Wardlaw & Davison, 1974). The major parameter adopted for these models is the relative duration of or the rate of reinforcement in the terminal link, or the relative reduction in time to reinforcement correlated with entry into the terminal links. Indifference is predicted when the schedules being compared have the same times or delay reductions to primary reinforcement. Hence, according to these models, our study and others on segmentation should obtain choice proportions of .50. Obviously this prediction is inconsistent with the data available. Of course, it may be possible to modify such models to incorporate the segmentation effect.

At least two models have made direct reference to the effect of segmentation on choice: the incentive theory proposed by Killeen (1982a, 1982b) and Vaughan's (1985) melioration model of choice. The incentive theory is a general model of behavior that has been extended to deal with choice in concurrent chains. Killeen (1982b) maintains that "behavior in the initial link of concurrent chained schedules is reinforced both by the direct (although delayed) effect of the primary reinforcer and by the immediate (although diluted) effects of the conditioned reinforcers (terminal link cues)" (p. 218). In effect, three factors are considered to be important for predicting choice in the concurrent chains: the overall rate of reinforcement, the delay of the primary reinforcer in the terminal link, and the terminal-link stimulus as a conditioned reinforcer. Incentive values of each of these factors have been expressed in mathematical terms (see Killeen,

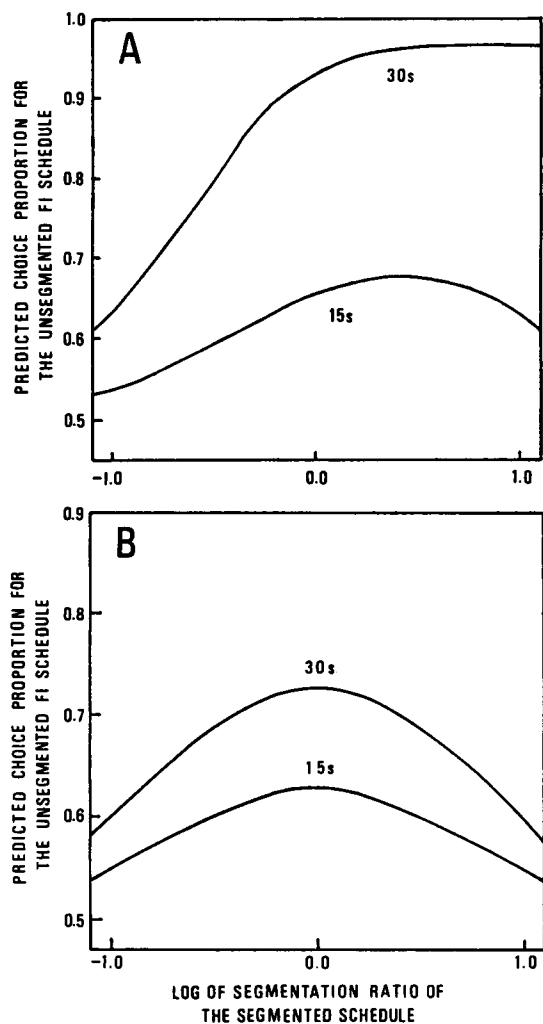


Fig. 3. The predicted choice proportion for the segmented FI schedule as a function of the logarithm of the segmentation ratio of the segmented schedule. The functions for two terminal-link durations (15 s and 30 s) are shown. Panel A shows the functions predicted by the incentive theory (Killeen, 1982b). Panel B shows the functions predicted by the melioration model of choice (Vaughan, 1985).

1982b). The influence on behavior by the primary reinforcer is said to decay with time at a rate ' q .' To account for segmented chained schedules in the terminal link, Killeen (1982b) assumes that the component not contiguous with the reinforcer (C1) has little incentive value but only serves to delay access to the conditioned reinforcer (S2). Given the above assumption concerning the function of C1, the incentive theory predicts that, for a given duration of the final component (C2), preference

for the unsegmented schedule will be a positive function of the C1 duration (in the segmented schedule). The situation is more complicated, however, when the total terminal-link duration (C1 + C2) is held constant because increasing the duration of C1 necessarily decreases the duration of C2. Thus, because the conditioned reinforcing value of C2 is assumed to be inversely related to its duration, moving the segmentation point closer to primary reinforcement increases the delay to the conditioned reinforcer (C2) while simultaneously enhancing the value of the conditioned reinforcer. Preference for the unsegmented schedule, then, is the result of two opposite-sloped functions. By invoking the appropriate equations (equations 5, 7, and 14 from Killeen 1982b), we calculated the choice proportions predicted by the incentive theory over a range of segmentation ratios similar to those used in the present experiment. When applying Equation 14, the durations of C1 and C2 were substituted for t_D and t_O , respectively. To be consistent with Killeen's original calculation, $q = .24$ was also used. (If q were set to a smaller value such as .12, the model would predict preference reversal at large segmentation ratios with the 15-s terminal link; however, a smaller q value would cause a gross underestimation of the preference predicted.) The resulting values for two terminal-link durations (15 s and 30 s) were plotted in Figure 3 (Panel A) showing preference as a function of the logarithm of the segmentation ratio. From Figure 3 (Panel A), it can be seen that the predicted choice proportions vary directly with increasing segmentation ratio up to a point and then level off for the long (30 s) terminal link and slightly decline for the shorter (15 s) one. In addition, the 30-s function always has values greater than the 15-s function. Although this predicted ordering of preference is consistent with the data, the predicted functions shown in Figure 3 (Panel A) differ in a number of respects from those obtained by the present experiment (see Figure 1). Our data show that preference varied inversely, instead of positively, with increasing ratio. In fact, the predicted functions are more like mirror images of those presented in Figure 1.

Vaughan's (1985) melioration model of choice is another theory that has dealt explicitly with the segmentation data. Melioration refers to the process in which an organism,

when confronted with two or more alternatives, always switches to the more favorable local rate of reinforcement being received (Herrnstein & Vaughan, 1980; Vaughan, 1981). To translate the process into a mathematical model, Vaughan (1982) first proposed to derive melioration in a way similar to the Rescorla and Wagner (1972) model for classical conditioning. Hence the value of a key stimulus as a conditioned reinforcer is a negatively accelerated function of the rate of the primary reinforcer it signals. Vaughan (1985) then assumes the unconditioned value of the stimulus to be zero. The resulting function is a simple hyperbola with the value of the primary reinforcer as its asymptote (cf. Gibbon, 1977). The rate at which the stimulus value approaches the asymptote is specified by the parameter "a." It has been suggested that $a = .20$ be used for an FI schedule and $a = .10$ be used for a VI schedule. For concurrent schedules, the values of each key can be evaluated to prescribe the direction of change in time allocation between keys. Melioration requires such changes to continue until the values of both keys become equal. At the equilibrium state, the particular distribution of time relative to the two concurrent schedules represents the choice proportion.

By the same token, the melioration model extends easily to the quantitative analysis of choice in concurrent-chains experiments. However, certain assumptions must be made about the nature of the terminal-link stimuli: "the value of an initial link is assumed to be functionally related to the value of a terminal-link stimulus, which in turn is assumed to depend on the value of reinforcement as well as on the rate at which reinforcement occurs, or equivalently, on the duration of the terminal-link stimulus . . ." (Vaughan, 1985, p. 390). To evaluate the value of an initial-link key stimulus, the calculation must be conducted in a backward manner starting from the primary reinforcer at the end of the terminal link. Upon determining the value of the primary reinforcer, the conditioned reinforcing values of the terminal-link and initial-link stimuli can be evaluated in successive order, respectively. For a pair of equivalent schedules in the terminal link, Vaughan's formulation predicts preference for the less segmented schedule over the segmented one because the initial-link key stimulus derives its reinforcing

value from a weaker reinforcer, S2, which is itself a conditioned reinforcer. Presumably, the reinforcing value of S1 is less potent than that of the unsegmented schedule stimulus that directly accompanies the primary reinforcer. How does this formulation fare with the present data? We calculated values corresponding to the segmented and unsegmented terminal-link stimuli by applying Vaughan's (1985) Equations 7 and 9 and then substituted these into Equation 10 to obtain the choice proportions. As stipulated by Vaughan, the parameter a was set at .20. The predicted choice proportions for the 15-s and 30-s durations were plotted in Figure 3 (Panel B) as a function of the logarithm of segmentation ratio.

These functions are bell-shaped curves with peaks at the ratio of 1:1, and they approach the asymptote of indifference (.50) for both increasing and decreasing ratios. By comparing Figure 3 (Panel B) with Figure 1, it becomes apparent that melioration only partly describes the present data. The model correctly predicts more extreme preferences with the longer terminal link. Also, the predicted decline in preference at segmentation ratios above 1:1 is consistent with our findings. Nevertheless, there are some discrepancies. First, melioration predicts decreasing preference with decreasing segmentation ratios (for ratios lower than 1:1), whereas the obtained preference increased with decreasing ratios. Second, the model tends to underestimate the size of preference for the unsegmented schedule, especially for the longer terminal link (30 s). Third, no reversal is predicted by melioration for the given terminal-link durations and segmentation ratios.

In the process of fitting our data to the incentive theory and the melioration model, we have, once again, demonstrated the difficulty of developing a comprehensive quantitative model of choice (cf. Killeen, 1982b). It is difficult to be certain whether the discrepancies between data and predictions are due to inadequacies of the fundamental assumptions or to inadequacies in the particular mathematical representations of those assumptions.

A possible problem encountered by both models in accounting for the present data might have been the assumption concerning the exact nature of S1 in a chained schedule. The influence of S1 in a chain may not be construed solely in terms of the temporal separation be-

tween the initial link and primary reinforcer. S1 may serve a role greater than that of filling a delay to the access of the conditioned reinforcer, S2 (Killeen, 1982b), or to a weaker conditioned reinforcer (Vaughan, 1985) for responding in the initial link. In fact, it makes intuitive sense to assume S1 in the chain to be aversive with respect to the stimulus correlated with the simple counterpart in the terminal link. Numerous nonchoice studies have reported the aversiveness of S1 in a chained schedule (e.g., Blanchard, 1975; Dinsmoor, Lee, & Brown, 1986; Findley, 1962; Frieman & Thomas, 1970; Kaufman & Baron, 1969; Thomas, 1966). One example was provided by Kaufman and Baron (1969) who, in one of a series of experiments, trained rats to respond under a chained schedule of reinforcement. Later, responses produced either S1, S2, or a neutral stimulus instead of the reinforcer. For the S1-contingent group, lever pressing was reduced below the level of the neutral-stimulus contingent control group. Hence it was concluded that within a chain, S1 acquired aversive properties and was not simply nonreinforcing. More recently, Dinsmoor et al. (1986) used an escape paradigm to demonstrate the negative reinforcing property of the early segments in an extended or multiple-component chain. Initially, pigeons' pecking was autoshaped, using a sequence of four colors presented on the same key, followed by food. At a later stage of training, pecks on the key could terminate the original key color and produce a replacement color. Otherwise, pecking would not affect the time to food delivery. It was found that pecking decreased in the presence of the color last in the sequence but increased in the presence of the first. This behavior of escaping from S1 was attributed to the fact that S1 always signaled the absence of food and therefore might have acquired aversive characteristics. If the preference away from a chained schedule can be deduced from the aversiveness of S1, a quantitative model incorporating this process should be able to account for the previous data on segmentation as well as the present data.

In conclusion, the present experiment joined other studies on segmentation (Duncan & Fantino, 1972; Fantino, 1983; Leung & Winton, 1985, 1986) in showing the adverse effect on choice of segmenting a schedule. But the most significant finding is the demonstration

of the segmentation ratio as a potent factor in affecting schedule preference. Based on evidence from nonchoice studies, it has been suggested that S1 in a chain may possess aversive instead of conditioned-reinforcing properties (see also Dinsmoor et al., 1986). Incorporating this assumption may allow quantitative models to better predict choice between segmented schedules and their unsegmented counterparts. However, one foreseeable difficulty concerns the assignment of an appropriate value to S1. So far, researchers have found various ways to demonstrate the aversiveness of S1. But the problem remains as to how this effect can be quantified in relation to other parameters such as the rate of primary reinforcement. The answer to this question must await future empirical investigation.

Traditionally, research on chains (e.g., Kelleher & Gollub, 1962) has emphasized the importance of S2 in controlling performances in earlier components, and the role of S1 remained obscured. Perhaps the study of segmentation effects has opened up a new avenue from which the properties of S1 can be examined. Finally, the possibility of preference reversal favoring the segmented schedule is well worth pursuing. According to the present findings, higher segmentation ratios may be conducive to this effect. From a technical point of view, highly extreme ratios are easier to program if the time to reinforcement is extended. Hence future research may consider employing a terminal-link duration longer than those used here.

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APPENDIX

For each subject, absolute rates of responding on both FI and chain keys during the initial link of the concurrent chains. The IRIs and segmentation ratios in the terminal-link chained schedules are also shown.

Con- dition	Terminal- link chain		Initial-link rates (per minute)							
			P14		P27		P34		P37	
	IRI	Seg. ratio	FI key	Chain key	FI key	Chain key	FI key	Chain key	FI key	Chain key
1	15	1:14	33.7	16.4	44.0	13.1	40.7	15.8	29.7	4.1
2	15	1:2	29.6	13.9	50.9	25.1	38.6	16.5	26.5	7.5
3	15	1:1	30.2	17.0	52.6	27.1	40.2	20.7	25.1	9.3
4	15	2:1	28.4	21.4	36.1	27.2	36.4	23.3	24.3	10.9
5	15	14:1	30.5	22.1	39.5	33.6	31.0	21.5	19.9	14.4
6	30	1:14	28.6	1.8	37.4	1.2	32.5	0.3	19.3	0.2
7	30	1:2	26.2	0.8	35.8	2.3	33.9	1.4	17.0	0.3
8	30	1:1	30.7	2.3	35.1	3.9	29.6	1.9	15.4	1.9
9	30	2:1	24.0	5.3	29.6	12.7	32.1	6.6	12.6	7.1
10	30	14:1	14.8	16.0	22.0	28.0	17.3	16.0	9.9	14.2