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THE SEVERAL ROLES OF STIMULI IN TOKEN REINFORCEMENT

CHRISTOPHER E. BULLOCK
UNIVERSITY OF FLORIDA

AND

TIMOTHY D. HACKENBERG
REED COLLEGE

Three experiments were conducted with pigeons to identify the stimulus functions of tokens in second-order token-reinforcement schedules. All experiments employed two-component multiple schedules with a token-reinforcement schedule in one component and a schedule with equivalent response requirements and/or reinforcer density in the other. In Experiment 1, response rates were lower under a token-reinforcement schedule than under a tandem schedule with the same response requirements, suggesting a discriminative role for the tokens. In Experiment 2, response rates varied systematically with signaling functions of the tokens in a series of conditions designed to explore other aspects of the temporal-correlative relations between tokens and food. In Experiment 3, response rates were reduced but not eliminated by presenting tokens independent of responding, yoked to their temporal occurrence in a preceding token component, suggesting both a reinforcing function and eliciting/evocative functions based on stimulus–food relations. Only when tokens were removed entirely was responding eliminated. On the whole, the results suggest that tokens, as stimuli temporally correlated with food, may serve multiple stimulus functions in token-reinforcement procedures—reinforcing, discriminative, or eliciting—depending on the precise arrangement of the contingencies in which they are embedded.

Key words: token reinforcement, second-order schedules, chained schedules, multiple schedules, fixed-ratio schedules, key peck, pigeons

Token-reinforcement procedures have a long history in both laboratory and applied realms, with laboratory research dating to the 1930s (Wolfe, 1936; Cowles, 1937), and applied work to the 1960s (Ayllon & Azrin, 1968; Hackenberg, 2009, for a review). Tokens are normally conceptualized as conditioned reinforcers, based on their correlation with other reinforcing events and activities for which they are exchanged, but the empirical evidence bearing on this function is surprisingly sparse.

Most of the evidence bearing on the reinforcing functions of tokens comes from research in which tokens have been shown to produce effects comparable to other reinforcers (Kelleher, 1958; Malagodi, 1967). Kelleher (1958), for example, showed that fixed-ratio (FR) schedules of token delivery engender response patterning comparable to that produced by simple FR schedules of food delivery, supporting the view of tokens as conditioned reinforcers. More recently,Bullock & Hackenberg (2006) examinedtoken-reinforced behavior as a function of FR token-production ratio (the number of responses required to produce a token) and FR exchange-production ratio (number of tokens required to produce an exchange period). The token-production and exchange-production FRs were manipulated parametrically across conditions. Response rates decreased, and preratio pausing increased, with increases in both FR schedules, comparable to effects seen with simple FR schedules.

The general comparability of the token-production FR performance to simple FR performance suggests that the tokens served a reinforcing function. As with other conditioned

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*Correspondence to: Correspondence may be addressed to the first author at the Kennedy Krieger Institute, Behavioral Psychology Department, 720 Aliceanna Street, Baltimore, MD 21202. (e-mail: Bullockc@KennedyKrieger.org).

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reinforcers, however, the tokens also came to serve important discriminative, or signaling, functions. The clearest evidence of this comes from data on the temporal distribution of behavior across token-production segments within an exchange-production ratio. For example, when multiple tokens are required prior to exchange, response rates are graded in proximity to the exchange period: Low rates in the early token-production segments give way to higher rates in segments closer to exchange and food (Foster, Hackenberg, & Vaidya, 2001; Foster & Hackenberg, 2004; Bullock & Hackenberg, 2006).

Such behavior closely resembles that seen on extended chained schedules of reinforcement (chained schedules with more than two links: Kelleher & Gollub, 1962; Kelleher, 1966). Like token schedules, chained schedules involve sequences of schedule components, with signaled component transitions correlated with progression through the overall sequence. As stimuli delineating temporal proximity to food, such transitions have been shown to serve reinforcing, discriminative, and eliciting functions (Kelleher, 1958; Ricci, 1973). To date, however, little research has examined the stimulus functions of tokens in token-reinforcement procedures. Such an analysis is long overdue because token-reinforcement procedures have some distinctive properties that make them especially useful for revealing behavioral functions of stimuli embedded in complex schedule arrangements (Hackenberg, 2009).

The present research was undertaken to investigate some stimulus functions of tokens in token-reinforcement procedures. The general strategy was to decompose a token-reinforcement procedure into some of its component parts, comparing and contrasting behavior under standard token-reinforcement schedules with that maintained under several token-schedule variants—otherwise comparable schedules but with relations between tokens and food altered systematically. To accomplish this, a multiple schedule was used, in which behavior was studied across two alternating components within a session, each correlated with a distinct stimulus. A standard token-reinforcement schedule was present in one component, whereas a token-reinforcement schedule variant—with tokens and/or token–food correlations varied—was present in the other (alternate) component. Differences in rates and patterns of responding in the token versus alternate component would indicate some functional role for the tokens. Determination of the precise role(s) of the tokens would depend on the size and direction of the effects relative to the token component.

Prior research on token reinforcement has typically used manipulable tokens, such as poker chips and marbles, that are deposited in a receptacle during exchange periods (Hackenberg, 2009). Such tokens are in a subject's possession until deposited, and there is no obvious way to remove a token once it has been earned. This poses problems for a study of the stimulus functions of the tokens, as it severely constrains the types and ranges of token–food relations open to examination (see Breland & Breland, 1961), for examples of some of the problems faced when using manipulable tokens). Such problems can be circumvented, however, with nonmanipulable tokens.

To that end, the present experiments utilized token-reinforcement methods originally developed by Jackson & Hackenberg (1996) with nonmanipulable tokens—stimulus lamps mounted in a horizontal array above the response keys in an otherwise standard experimental chamber for pigeons. These methods have more recently been refined and extended to other procedures, including concurrent schedules (Hackenberg & Vaidya, 2003; Foster & Hackenberg, 2004; Yankelevitz, Bullock, & Hackenberg, 2008; Andrade & Hackenberg, 2012; Lagorio & Hackenberg, 2012; Mazur & Biondi, 2013), single-alternative token-reinforcement schedules (Bullock & Hackenberg, 2006; Foster et al., 2001), and conditioned punishment procedures (Pietras & Hackenberg, 2005; Raiff et al., 2008). As with manipulable tokens, such token lights can accumulate across a session, and in standard arrangements there is a correlation between number of tokens and the amount of food for which they can be exchanged. Unlike token systems with manipulable tokens, however, token lights can be quickly and easily presented and removed, and can be arranged in various combinations and configurations. This opens the investigation of stimulus functions of tokens to much finer-grained analyses like those reported here.

Experiment 1

One method for assessing the functions of stimuli in an extended-sequence schedule is to employ an equivalent tandem schedule. A tandem schedule, when used as a control condition, typically arranges for the segment response requirements and schedules identical to those of the sequence schedule of interest, with the exception that there are no added stimuli delineating the transitions between sequences (Kelleher & Gollub, 1962).

For example, Jwaideh (1973) examined pigeons' responding under extended FR chained schedules, in which completing individual FR schedules produced a stimulus change (change of key color) and completing all of the component FR schedules produced food. To assess the effects of the stimulus changes, a tandem procedure was employed in which the response requirements were identical, but no stimuli were presented following the completion of the component FR schedules. The only difference was whether each FR sequence, or link, was (chained) or was not (tandem) correlated with a distinct stimulus. Response rates under tandem conditions were generally higher than equivalent chained conditions, mainly due to weak behavior in the early links of the chain, a finding consistent with other research (Thomas, 1964; Catania et al., 1980). Further, response rates under the chained schedule were ordered with respect to the proximity to food, strongly suggesting a discriminative function of the stimuli: Stimuli in the later links proximal to food controlled higher response rates than stimuli in early links remote from food.

The present experiment followed a similar logic, comparing performance in a token-reinforcement schedule to that in a tandem schedule equivalent in all respects except for delivery of tokens within an exchange cycle. The token-production schedule remained constant at FR 50, a value at which graded patterns of responding across successive token-production segments have been seen in prior research. This graded pattern is an important indicator of discriminative functions of added stimuli such as tokens. The exchange-production FR was varied across conditions in a manner consistent with prior research (Foster et al., 2001; Bullock & Hackenberg, 2006;). The present experiment may therefore be conceptualized as a systematic replication (Sidman, 1960), but with tandem-control conditions to assess the stimulus functions of the tokens.

Half the pigeons' sessions were conducted primarily in boxes with small tokens (light emitting diodes, or LEDs) whereas sessions for the other half were conducted in boxes with somewhat larger tokens (jeweled stimulus lights, 1.5 cm in diameter). Prior published work on token-reinforcement schedules in our laboratory used the small-token preparation, but we had suggestive evidence of more pronounced and systematic effects from the larger tokens. Comparing performances across the two different token types may shed additional light on this issue.

Method

Subjects. Six White Carneau pigeons (*Columba livia*) (numbered 907, 83, 832, 999, 910, 47) served as subjects. Only Pigeon 832 had prior experience with token-reinforcement schedules. Pigeons were individually housed under a 16.5 hr/7.5 hr light:dark cycle and had constant access to water and health grit in home cages. Pigeons were maintained at 80% ± 20 g of their free-feeding weights with supplemental postsession feeding. All procedures were reviewed and approved by the local IACUC.

Apparatus. Two standard three-key pigeon chambers with a modified stimulus panel served as the experimental apparatus. The first chamber (large token chamber) was 35 cm high by 31 cm long by 34.5 cm wide, and had a stimulus panel with three response keys centered horizontally 10 cm from the ceiling to the key center and 8 cm from the adjacent key(s) (center to center). A row of 12 evenly spaced stimulus lights with red caps, approximately 1.5 cm in diameter, was centered 7.5 cm above the response keys (center to center) and protruded 1.3 cm into the enclosure. The stimulus lights were always illuminated left to right, in sequential order, and served as tokens in this arrangement. Food was delivered through an opening centered 10.5 cm under the center key (approximately 5.5 cm wide and 5 cm tall). This box was also equipped with a Sonalert® that provided an auditory stimulus (0.1 s tone) that accompanied token onset and offset.

The second chamber (small token chamber) was 36 cm high by 50 cm long by 36 cm wide and the intelligence panel had three response keys, centered vertically 11.5 cm from the ceiling to the key center and 9 cm from each other (center to center). For this chamber, a stimulus array of 34 red, evenly spaced, light-emitting diodes (LEDs), 0.4 cm in diameter, were centered 5 cm above the keys and 1.25 cm apart from each other (center to center), and protruded 0.3 cm into the enclosure. The LEDs were always illuminated left to right, in sequential order. An electromechanical stepping switch (Lehigh Valley Electronics®, Model 1427) located on top of the chamber controlled LED illumination, the operation of which also provided auditory feedback each time a token was presented or removed. A food hopper opening was centered 11.5 cm below the left key (approximately 5.5 cm wide and 5 cm tall).

Both chambers included a houselight centered above the token array that provided diffuse illumination. When operative, side keys were illuminated green or yellow, and the center key red. Pecks with a force between approximately 0.11–0.14 N (small token box) and 0.13 N (large token box) were counted. A solenoid-operated hopper could be raised into the food opening, allowing access to mixed grain. A white light inside the hopper illuminated during the food presentation. A photobeam recorded head entry into the hopper. Continuous white noise and ventilation fans were active during experimental sessions to mask extraneous sounds. In a separate room a computer equipped with Med-PC® software controlled experimental events and collected data.

Procedure

Preliminary training. All pigeons were exposed to a series of training conditions (data not shown) prior to Experiment 1. Naïve pigeons were initially adapted to the experimental chamber with the houselight illuminated and were trained to eat food from the grain hopper. For those with no history of key pecking, pecks to the center key were shaped via reinforcing successive approximations. All pigeons were then exposed to an FR 1 schedule in which pecks on the red illuminated center key produced food. This was followed by sessions in which the left side key was illuminated; a peck on this key would darken the side key and illuminate the center key; a peck on the center key would darken the center key and produce food. This training arrangement lasted until pigeons were reliably pecking the side and center keys. This was followed by exposure to a multiple schedule with an FR 100 in effect during both components. Each pigeon was then exposed to several days of token–food pairings. These sessions consisted of the alternating illumination of the left side key within a session (randomly yellow or green). After the side key was pecked (FR 1) a token was illuminated and a tone was sounded, after which the side key darkened and the center key illuminated. A peck on the center key resulted in the darkening of one token and 1.5 s of food (timed from head into hopper). These sessions lasted for 64 reinforcers and were in effect for 10 days.

Standard procedure. Each session consisted of a two-component multiple schedule with two exposures to each component. Components occurred in a pseudorandom order such that both components had to be presented before one was repeated, with a component remaining in effect for 16 food deliveries. Components were separated by a 30-s blackout, or intercomponent interval (ICI). Sessions began with the illumination of the white houselight and left key (either green or yellow depending on component type, with colors counterbalanced across birds).

During the token components, tokens were earned according to an FR 50 token-production schedule (i.e., 50 responses produced one token) and exchanged according to a second-order FR exchange-production schedule. That is, the opportunity to exchange tokens for food occurred after earning a fixed number of tokens. The exchange-production schedule was varied systematically from FR 2 to 8 across conditions. Completing the exchange-production-ratio requirement produced an exchange period, during which the left key darkened and the center key illuminated red. A single response on this key darkened the rightmost token and raised the food hopper for 1.5 s. This exchange period remained in effect until all tokens earned that cycle had each been exchanged for food, followed by an immediate return to the token-production cycle (left key illuminated) or, following the 16th food delivery per component, the ICI.

During the tandem components reinforcement periods were produced by keypecks according to FR schedules. This FR schedule was set equivalent to the total responses required to produce an exchange in the token component. Following completion of the single FR (with no intervening tokens) in the tandem component, a number of tokens equal to that in the token component were illuminated and made available for exchange. In summary, the response requirement and token-exchange stimulus conditions were identical for the tandem and token components with the exception that no stimulus change occurred within the exchange-production ratio under the tandem schedule. That is, the tandem schedule was a simple fixed-ratio schedule matched to the overall number of responses in the token component. For example, when the token schedule was FR 4 (50; token production FR 50, exchange production FR 4), the tandem schedule was FR 200.

Table 1 lists the order of conditions and number of sessions per condition. Key colors were reversed under replications. Conditions lasted for at least 14 sessions and until response rates for each component were deemed stable via visual inspection. Data were generally considered stable when no monotonically increasing or decreasing trends were evident and the highest or lowest points were not present in the last five sessions of a condition.

Results

Figures 1 and 2 show for each pigeon the means and standard deviations of the running response rates (response rates factoring out pre-ratio pausing) and pre-ratio pausing, respectively, as a function of exchange-production FR across the final five sessions of each condition (note log scale for the y axis on Fig. 2). Graphs in the left and right columns of these figures show data for pigeons whose sessions were conducted primarily with smaller and larger tokens, respectively. Filled points represent data from token components, open points show data from tandem components, while unconnected points denote replications. The final conditions for several pigeons were replications across chamber type. Thus, for one condition, Pigeon 907 was run in the small-token chamber while for one condition Pigeons 999 and 832 were run in the large-token chamber. Data from these conditions are denoted by squares.

For two of the three pigeons studied in the large-token chamber (right panels of Figs. 1 and 2), response rates varied inversely, and pre-ratio pausing varied directly, with the value of the exchange-production ratio in both token and tandem components (to a lesser extent this was true for 907). For the three pigeons studied in the small-token chamber (left panels), similar effects on overall response rates were seen, but they were less clearly differentiated by component type (token vs. tandem); and in one case (Pigeon 999) the effects were reversed. (Also note that for 83, the error bar extends below the x axis. This is due to the use of a log scale starting at 1). In particular, response rates decreased under the FR 8 exchange schedule for all pigeons, with one pigeon (910) ceasing to respond entirely (this condition was eventually discontinued).

The data from replications and control conditions closely matched those from the

Table 1

Order of conditions and number of sessions per condition (in parentheses) for Experiment 1. Listed are the schedules in the token components, but each condition also included a tandem component with identical overall response requirement and reinforcer magnitude. See text for additional details.

Pigeon					
Small Tokens			Large Tokens		
832	910	999	47	83	907
FR 2[50] (17)	FR 2[50] (22)	FR 2[50] (19)	FR 2[50] (34)	FR 2[50] (35)	FR 2[50] (42)
FR 4[50] (22)	FR 4[50] (70)	FR 4[50] (56)	FR 4[50] (31)	FR 4[50] (14)	FR 4[50] (21)
FR 8[50] (37)	FR 8[50] (16)[c]	FR 8[50] (61)	FR 8[50] (33)	FR 8[50] (30)	FR 8[50] (26)
FR 4[50][a] (28)	FR 4[50][a] (39)	FR 4[50][a] (15)	FR 4[50][a] (19)	FR 4[50][a] (46)	FR 4[50][a] (49)
FR 4[50][a,b] (53)		FR 4[50][a,b] (34)			

[a] denotes a color reversal.

[b] denotes conditions conducted in large token box.

[c] denotes that a condition was not completed.

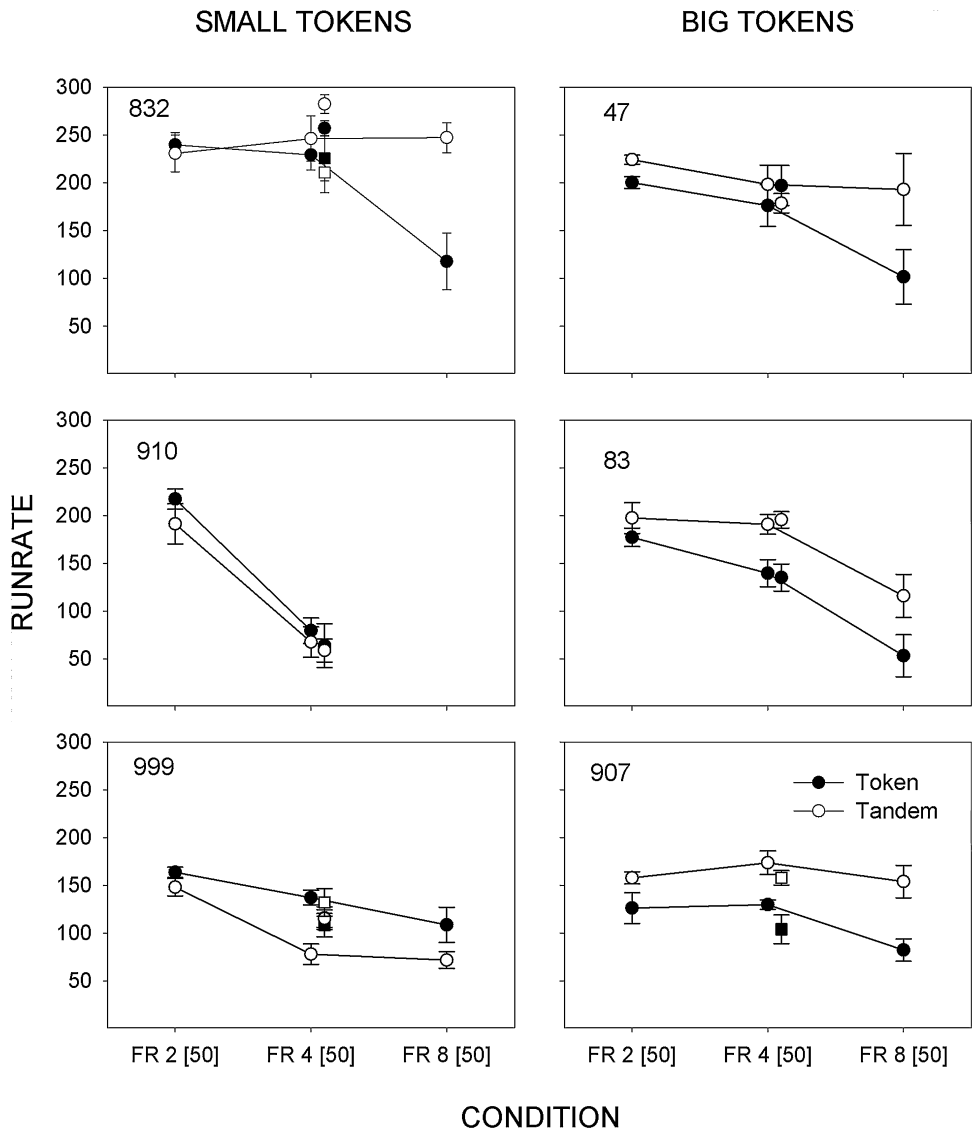

Fig. 1. Mean local responses per min (excluding pre-ratio pause) and standard deviations plotted as a function of exchange-production ratio from the last five sessions of each condition for each pigeon in Experiment 1. Left panels show the data from sessions conducted primarily in the small token box whereas right panels show data from sessions conducted primarily in the large token box. Open symbols represent data from tandem components, closed from token components; disconnected symbols represent replications, squares data from replications across different chambers and token sizes.

standard experimental conditions (with the exception of one instance for 999), demonstrating the reliability of the effects, and helping to rule out schedule-correlated stimuli (i.e., key color) as a controlling factor. The between-subject counterbalancing of key color helped to further minimize the influence of this variable. For those pigeons studied in the small-token box that received sessions in the large-token chamber, results did not appreciably differ across the two chambers in these conditions.

Figure 3 shows means and standard deviations of running response rates for each token-production segment (the ordinal position within the exchange-production cycle) for the three pigeons whose sessions were conducted primarily with the large tokens. Filled and open circles represent performance under token and

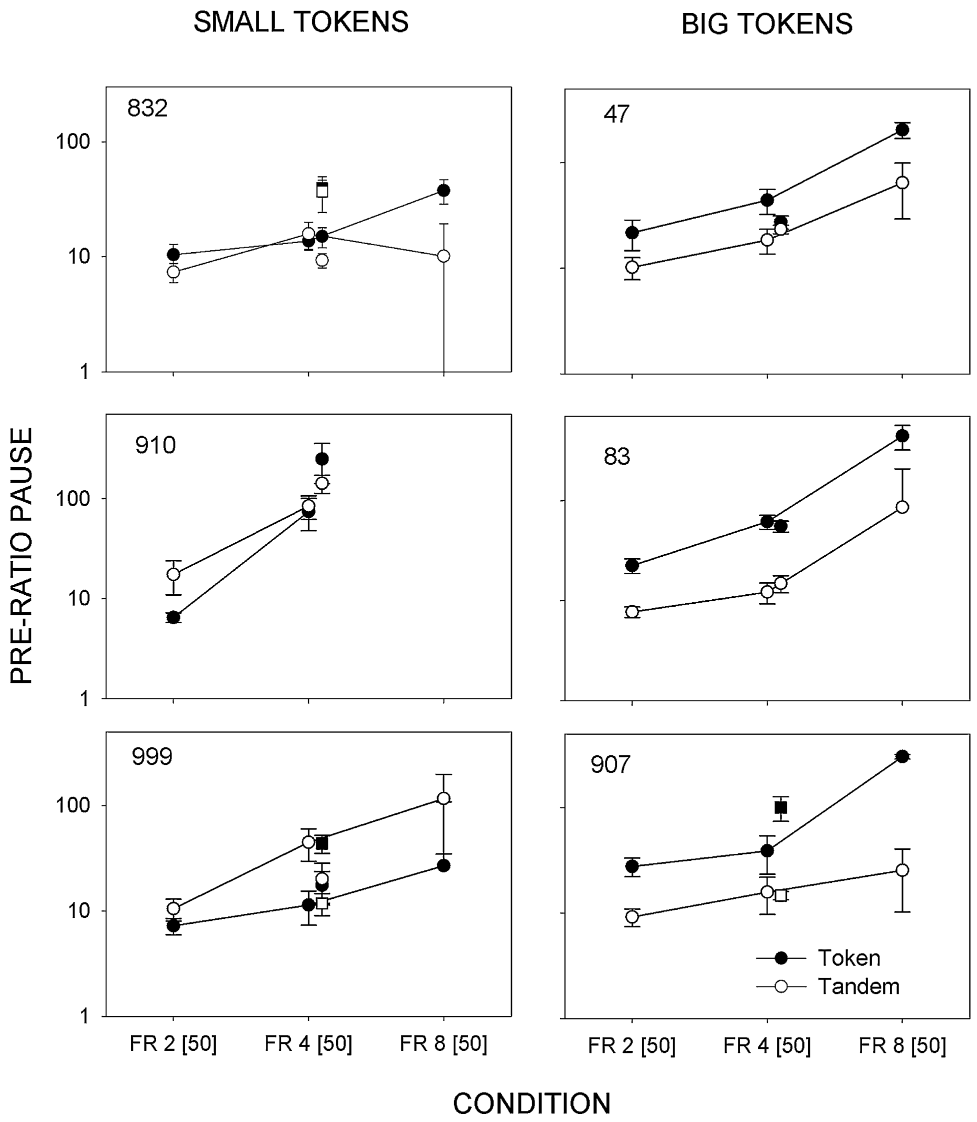

Fig. 2. Mean pre-ratio pausing and standard deviations plotted as a function of exchange ratio from the last five sessions of a condition for each pigeon in Experiment 1. Note that the y-axis is logarithmic. All other details as in Figure 1.

tandem components, respectively, while dashed lines indicate replications. For both tandem and token components across all exchange production schedules, initial-segment rates generally were low and increased as a function of number of tokens earned, reflecting strong control by proximity to food in both component types. The rates were generally higher in the tandem than in the token components, especially in larger FR exchange conditions. Response-rate disparities across the two components decreased with proximity to food. The pre-ratio pausing data (not shown) revealed a similar pattern: longest in the segments remote from exchanges and food. Data from the other three pigeons (small-token chambers) were generally similar, though the component differences were somewhat less pronounced.

Discussion

The primary findings from this experiment can be summarized briefly. Response rates varied inversely, and pre-ratio pausing directly, with the

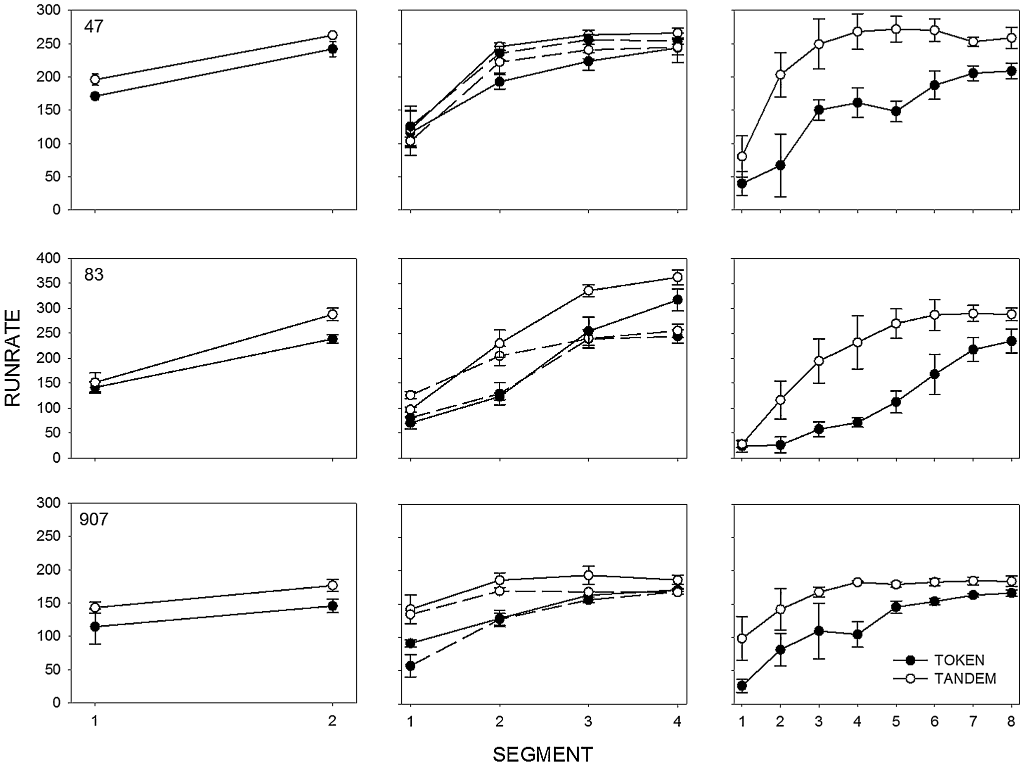

Fig. 3. Mean local responses per min (excluding pre-ratio pause) plotted as a function of token production segment from the last five sessions of each condition in Experiment 1 for the three pigeons whose sessions were conducted primarily in the large token box. Points from tandem components represent successive 50-response segments. Open symbols represent data from tandem components, closed from token components; solid lines represent original exposures, dashed lines represent replications.

FR exchange-production schedule, replicating previous findings with FR exchange-schedule manipulations (Foster et al., 2001 & Malagodi, 1978; Bullock & Hackenberg, 2006). For the pigeons studied in the large-token chamber, the token components generally produced lower response rates, and higher pre-ratio pausing, than the otherwise identical tandem components, a finding that is also consistent with prior research on extended-chained schedules (Jwaideh, 1973). The component-based differences were less consistent in the smaller-token chamber, though the overall response rate and pausing data were generally comparable.

That the component-related effects were generally stronger in the larger-token chamber is presumably due to greater salience of the larger tokens, which comprised approximately three times the surface area of the smaller tokens. Further, as mentioned earlier, the small token array was composed of 34 lights while the larger token array contained 12 lights. As such, the proportion of the total array illuminated with each large token presentation was roughly three times greater than when a small token was illuminated, a difference which might also have resulted in stronger effects with larger tokens. Switching from the small-token to the large-token chamber for a number of sessions did not appreciably alter the results. It is worth noting that these pigeons already had a long history with the smaller tokens, and this may have mitigated further differentiation. Differences may also have been more likely in the FR 8 exchange condition, where responding in general was more clearly differentiated across components.

Experiment 2

The temporal organization of behavior across the token-reinforcement schedules in the first experiment is similar to that seen in other token-reinforcement schedules with FR token-production and exchange schedules (Kelleher, 1958; Webbe & Malagodi, 1978; Foster et al., 2001; Bullock & Hackenberg, 2006) and in extended-chained schedules with FR components (Jwaideh, 1973). The present experiment sought to more systematically compare token-reinforcement and extended-chained schedules with respect to both overall response rates and temporal organization of behavior. This was accomplished both by (a) modifying the token-reinforcement schedule in ways that more closely approximate extended-chained schedules, and (b) altering the temporal-correlative relations between tokens and food.

In a relevant background experiment by Kelleher and Fry (1962), pigeons' responding was examined over a series of conditions involving a traditional chained schedule, a modified chained schedule in which the stimuli denoting each link varied from cycle to cycle, and a tandem control. The chained schedule was composed of three sequential fixed-interval (FI) schedules. It was found that, following a pre-ratio pause, responding occurred at a high, steady rate under the tandem schedule. Under the traditional chained schedule, responding was characterized by a long pre-ratio pause and low response rates in the first link, followed by progressively increasing rates in the second and third links. When compared to the first two links of the traditional chained schedule, response rates under the variable chained schedule were higher and pre-ratio pauses lower. Unlike performance under the tandem schedule, response rates were positively accelerated in the chained-schedule conditions, a finding indicative of a discriminative function.

In a similar vein, the present research manipulated several features of the stimulus–food relations in token-reinforcement schedules to assess the stimulus functions of the tokens. In one condition, *standard chain*, the token-reinforcement schedule was altered such that it was more procedurally similar to a standard extended-chained schedule. Tokens were presented at the completion of each FR link, but only one reinforcer was available during exchange. Token schedules differ from standard chained schedules in terms of the number of reinforcers available in the exchange period, or terminal link: one in the standard chained schedule and *x* in the token schedule (with *x* equal to the number of token-production segments). Comparing behavior under such standard chained schedules to behavior under token-based chained schedules will throw light on the role of the added reinforcers in the token schedule.

In a second condition, *reverse chain*, the standard token-reinforcement schedule was compared to one in which the tokens preceding an exchange occurred in the reverse order (i.e., with a token removed upon completion of each succeeding segment). Varying the order in which stimuli are presented in a token-reinforcement schedule may provide insights into the discriminative functions of the tokens, in particular, the correlation between the number of tokens and the amount of food available during the exchange period. If the tokens function mainly as conditioned reinforcers, and depend on pairing with food, then responding should be stronger in the standard token schedule than in the reverse chained schedule. Conversely, if the tokens serve mainly discriminative functions, then responding should be stronger in the reverse chained schedules, as the token-production segments all occur in the presence of one or more tokens.

In a third condition, *variable chain*, additional discriminative functions of the tokens were examined by weakening the correlation between token number and temporal proximity to an exchange period. Discriminative functions of the tokens arising from temporal relations to food would likely be reduced here, as the number of tokens per exchange cycle varied, and token number was therefore less reliably correlated with exchanges and food than on standard token schedules. Further, while the initial links would occur in the absence of tokens in both components, the variable duration of the initial links in the variable chain would be expected to attenuate pausing, thereby increasing overall response rates.

Method

Subjects and apparatus. Four White Carneau pigeons (*Columba livia*), numbered 47, 83, 832, and 999, served as subjects. All had previously served in Experiment 1 (Pigeons 47 and 83 in the large-token chamber and 832 and 999 in the small-token chamber), as well as an intervening set of conditions using a similar procedure, not reported here. The chamber with the larger tokens was the only one used in this experiment (i.e., the standard three-key pigeon chamber with a row of 12 evenly-spaced stimulus lights from Experiment 1).

Procedure

Similar to Experiment 1, a two-component multiple schedule was used in Experiment 2. Each component type occurred twice per session. In one component, a token-reinforcement schedule was in place while the other component consisted of a variant of a token schedule. In both components, an exchange period occurred after 200 responses; in the token components, tokens were produced after every 50 responses and exchanges after every four tokens (FR 4 [50]). Components were ordered pseudorandomly, with components remaining in effect for four exchange cycles. A 30-s ICI occurred between each component.

The token-variant component involved three variations on the standard token schedule: *standard chain*,*reverse chain*, and *variable chain*. In the *standard chain* component, a single food delivery was available at the end of the terminal link, but with all other features identical to a standard token-reinforcement schedule. That is, identical to the token-reinforcement component, tokens were produced according to an FR 50 and exchange periods occurred after four tokens were produced. The first exchange response, however, darkened all tokens and produced only a single 1.5-s food delivery.

The *reverse chain* component was identical to a standard token-reinforcement schedule with the exception that a token-production cycle began with four tokens and every 50 responses extinguished one. Thus the removal of tokens, rather than the presentation, was correlated with temporal proximity to exchange. Following the removal of the last token, four tokens were illuminated and an exchange period began.

In the *variable chain* component, responses produced tokens under a variable ratio (VR) 50 schedule (up to a maximum of 12). The number of tokens produced, however, was unrelated to number of responses per exchange period (always 200) or the number of reinforcers available during exchange (always four). In these components it was possible to enter an exchange with fewer or greater than four tokens. During the exchange period, however, four reinforcers were available, with each exchange response darkening a token. If more than four tokens had been produced, then additional center key responses were required to darken the remainder before another token-production cycle began. If fewer than four tokens had been produced, responses on the center key simply continued to produce food until four reinforcers had been obtained. The uncompleted VR value at the end of a cycle was used as the first for the next cycle.

Sessions began with the illumination of the white houselight and the left or right side key (either green or yellow depending on component type). Conditions were in effect for a minimum of 11 sessions and until response rates were deemed stable across the last 5 sessions via visual inspection. Table 2 lists the order of conditions and number of sessions per condition.

Results

Figure 4 shows, for each pigeon, mean and standard deviation of overall responses per min for both component types across conditions. The filled bars represent response rates under the token-reinforcement schedule whereas the open bars show rates under the three token-variant schedules. For all pigeons, response rates were lower in the standard chained than in the token-based chained schedule component. For three of four subjects under the *reversed* and *variable chain* conditions, this relationship was reversed, with response rates lower in the token-

Table 2

Order of conditions and number of sessions per condition (in parentheses) for Experiment 2.

Pigeon			
47	83	832	999
Standard chain (47)	Standard chain (24)	Standard chain (17)	Standard chain (28)
Reverse chain (26)	Reverse chain (17)	Reverse chain (38)	Reverse chain (11)
Variable chain (35)	Variable chain (23)	Variable chain (30)	Variable chain (26)

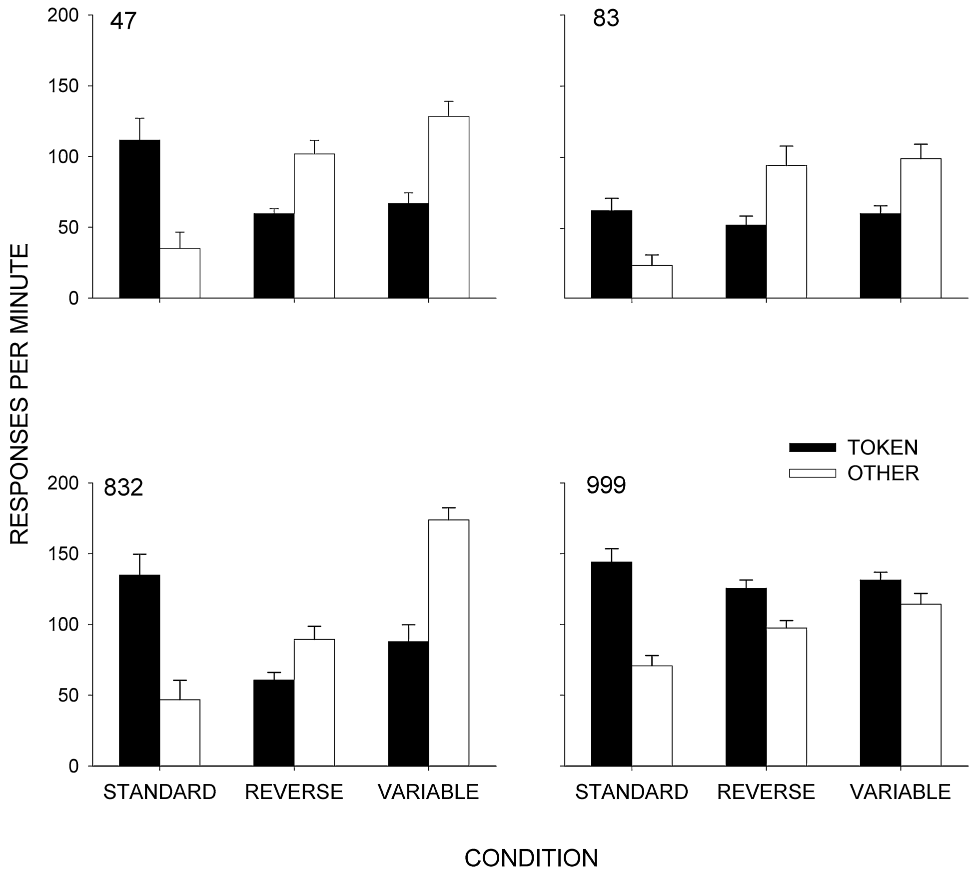

Fig. 4. Mean overall responses per min and standard deviations from the last five sessions of a condition for each pigeon in Experiment 2. Filled bars represent data from the token component whereas open bars represent data from the component varied across conditions.

schedule component. The lone exception in these latter conditions was Pigeon 999, for whom response rates remained higher in the token component. Even for this subject, however, response rates were slightly higher under the *variable chain* and *reverse chain* than in the standard chain components, perhaps reflecting the higher reinforcer magnitudes in these conditions (four vs. one food deliveries).

Figure 5 shows means and standard deviations of running response rates in both components across 50 successive response segments. Filled circles represent responding under the token-reinforcement components and open circles under the components with the chain-schedule variants. Response rates were generally graded across successive FR segments, with rates in the two components converging in the later segments. The main effect of reinforcer magnitude (token vs. standard chain, left panels) was that of elevating the rates in the early segments. In some cases (Pigeon 999 and to some extent for Pigeon 832), decreasing reinforcement magnitude produced a more graded pattern across token-production segments. Under the *reverse chain* (middle panels) and *variable chain* (right panels) components, response rates early in the cycle increased compared to those in the opposing token schedule for all subjects except Pigeon 999. Response patterning across the cycle was similar for both the *reverse-chain* and *variable-chain* components: Response rates were low in the initial segment and remained somewhat constant (Pigeons 832 and 999) or gradually increased (Pigeons 47 and 83). Response rates in the opposing token components, however, were marked by a more

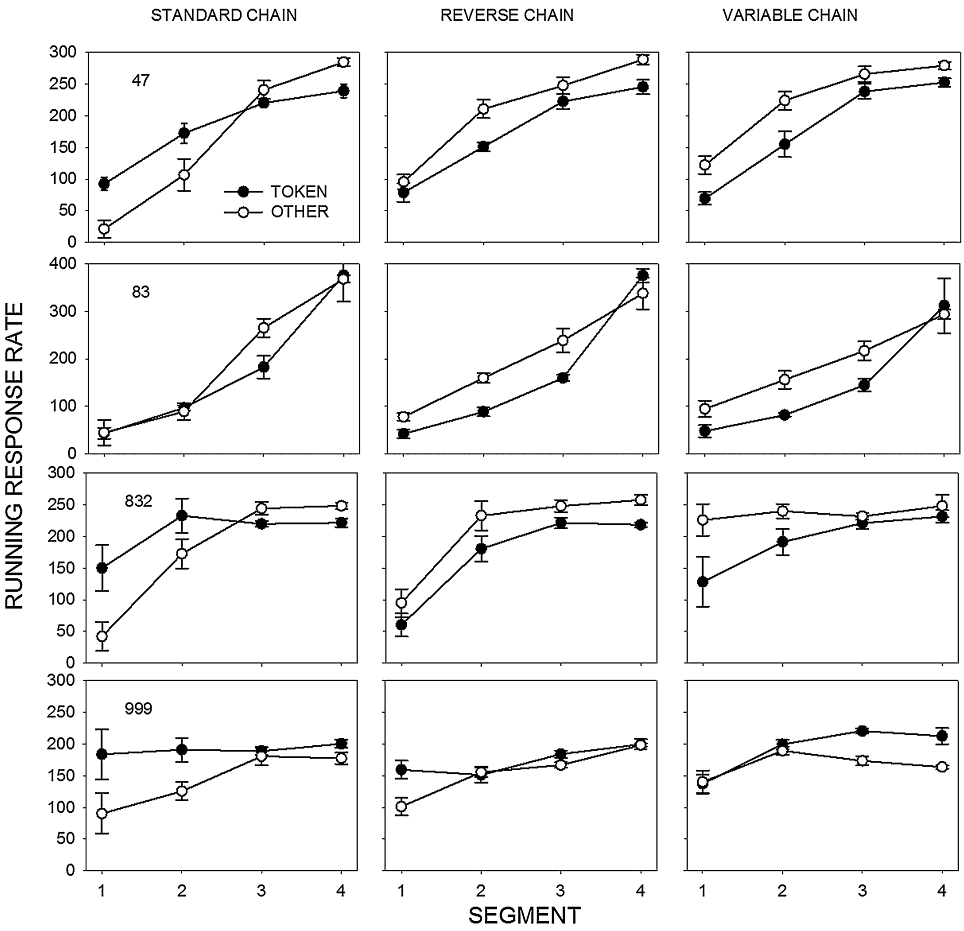

Fig. 5. Mean responses per min (excluding pre-ratio pause) plotted as a function of token production or 50-response segments from the last five sessions of a condition in Experiment 2. Open symbols represent data from token variant components whereas closed symbols represent data from token components.

accelerated function than the other component in six of eight cases. Similar to the previous experiments, pre-ratio pausing (not shown) in both components was characterized by long pauses in the initial segment giving way to short, constant pauses thereafter.

Discussion

The standard chained schedule produced lower response rates, compared to the opposing token-based schedule, a joint product of longer pre-ratio pauses and lower response rates early in a cycle. Data from the standard chained component indicated that responding was sensitive to reinforcer magnitude, with rates consistently higher in the standard token component (four food deliveries) than in the standard chained component (one food delivery). This could be due to the greater reinforcer magnitude in the token component or to the correlation between number of tokens and reinforcer magnitude in that component. Although there was a difference in running response rates between the standard chained and token-based chained schedules, the qualitative patterns of responding were generally similar, with response rates increasing across a cycle as tokens accumulated. This raises the possibility that discriminative properties of chained and token-reinforcement schedules are similar, but that reinforcer magnitude shifts the function.

That response rates in the initial links of the *reverse chain* remained low relative to later links suggests that low response rates in early links are not simply due to the absence of tokens. These data speak to the importance of the correlation of the tokens with temporal proximity to food. That response rates increased in the *variable-chain* component relative to the token component for three of four subjects suggests that the correlation between number of tokens and proximity to exchange is an important determinant of any discriminative functions the tokens may acquire. These results are similar to those of the variable-chain condition from Kelleher & Fry (1962), and suggest that the simple presence or absence of a given number of tokens or type of added stimulus is arbitrary: What matters is the temporal relation between those stimuli and food.

Experiment 3

The results of the first two experiments provide strong evidence that tokens serve discriminative functions based on their temporal relations to food. That is, they occasion responses relative to the proximity to food they signal. The present experiment sought to determine the necessity of the operant contingencies in the signaling functions of the tokens.

There is evidence that response-independent presentation of prefood stimuli can generate responses (autoshaping, or sign tracking), and that the rate of such responding is graded in relation to proximity to food. Ricci (1973), for example, examined pigeons' keypecking under a procedure in which 4-s access to grain was presented after either 120 s of a single keylight color, or a series of four keylight colors shown for 30 s each. Response distributions under the four-color conditions were graded, with response probability increasing as a function of the temporal proximity of that stimulus to food. By contrast, responding under the one-color conditions was much more uniform throughout the 120-s interval. It appears that even in the absence of an operant contingency, the stimuli in such serial autoshaping procedures may also have discriminative effects similar to token and extended-chained schedules; that is, a positively accelerated pattern of responding under sequential arrangements of stimuli temporally related to food.

Such findings raise the possibility that responding on schedules of token reinforcement may be maintained in part by token–food relations apart from the operant contingencies in the presence of the tokens. The present experiment was designed to investigate this possibility. In one component of a multiple schedule, tokens were presented response-independently, yoked to their temporal occurrence in the immediately prior token-reinforcement component. Under simple schedules, response-independent reinforcement breaks the dependency between responding and food production, resulting in lower response rates (Lattal, 1972). If the stimulus function of the tokens was primarily a function of operant contingencies then presenting them response- independently should similarly result in a substantial decrease of response rates. On the other hand, if tokens served an eliciting function, in the manner of serial autoshaping, one would expect some maintenance of responding that should be graded in relation to temporal proximity to food. These conditions in the present experiment were designed to assess the degree to which responding maintained under token-reinforcement schedules is a product of the temporal relations between tokens and food (a stimulus–stimulus relation) apart from the contingent production of tokens (a response–reinforcer relation).

Method

Subjects and apparatus. The subjects and apparatus were the same as in Experiment 2.

Procedure

Similar to the other experiments, a two-component multiple schedule was used with a token-reinforcement schedule in one component. In the other (*Yoked*) component, tokens and food were delivered in the same temporal sequence as in the token-reinforcement component. Each component occurred twice and lasted for four exchange cycles. A 30-s ICI separated successive components. Sessions began with the illumination of the white houselight and side key associated with the token component (either green or yellow). In the token component, tokens were produced every 50 responses and exchanges after every four tokens (FR 4 [50]). In the yoked component, tokens and exchange periods were presented response-independently, yoked to the times they occurred in the preceding token component. The token components always occurred first and third, the yoked component second and fourth, to permit yoking to the most recently completed token component.

Two other conditions consisted of (a) holding the token-production key color constant across both components (*Mixed Schedule*), and (b) removing the tokens entirely from the token-production cycle of the yoked component (*Yoked No-Token*). In this latter condition, four tokens illuminated immediately prior to the exchange period while the number of food deliveries (4) and delays to the exchange period were equal to those in the token component. Conditions were in effect for a minimum of 14 sessions and until response rates were deemed stable across the last 5 sessions via visual inspection. Table 3 lists the order of conditions and number of sessions per conditions.

Results

Figure 6 shows response rates (exclusive of pre-ratio pausing) for each pigeon across the final five sessions in each condition. Filled bars show performance from the token components whereas open bars show performance from the yoked components. Response rates in all standard token components were higher than in comparable yoked-component variations. Although response rates were reduced in the yoked components, they continued to occur at a moderate rate (50–100 responses per min). When the tokens were removed entirely under *Yoked No-Token* conditions, response rates decreased to very low levels. In the yoked component with the token-production key color the same as the opposing token component (*Mixed*), response rates were either comparable to, or slightly lower than, those in the standard yoked-token conditions for all four pigeons.

Figure 7 shows means and standard deviations of running response rates in each component type across successive segments in the exchange cycle. Segments consisted of either 50 responses (token component) or the equivalent time periods (yoked component). Response patterning under the token components was graded, increasing as a function of the number of tokens earned and proximity to food. Under the standard token-yoked conditions, responding within a cycle was characterized by low rates in the initial segments, followed by an increasing rate in the later segments, converging on rates in the comparable token components. For all pigeons under the *Yoked No-Token* components response rates were equally low for all four segments.

Figure 8 shows the cumulative frequency of obtained delays (the time between the immediately preceding response and token delivery) for each token segment plotted as a function of delay size. Only instances in which a response occurred within a given segment were included in this analysis. This figure plots each response–token delay, ordered from smallest to largest with respect to obtained delay, as a function of time. When arranged in this manner, the graph shows the number of delays less than a particular duration of time while also showing each individual obtained delay. The reader should note that for some segments, the number of obtained delays plotted is less than the number of exposures to that segment (40) over the last five sessions of the condition. This is because some subjects did not respond at all during the early segments on some occasions. The response–token delays were longest in the first segment and decreased across segments within an exchange cycle. During the final segments the obtained delays were relative short, with almost all less than 1 s.

Table 3

Order of conditions and number of sessions per condition (in parentheses) for Experiment 3.

Pigeon			
47	83	832	999
Yoked (34)	Yoked (35)	Yoked (50)	Yoked (25)
No token (14)	No token (15)	No token (17)	No token (14)
Yoked (16)	Yoked (20)	Yoked (22)	Yoked (32)
Mixed (17)	Mixed (30)	Mixed (18)	Mixed (18)

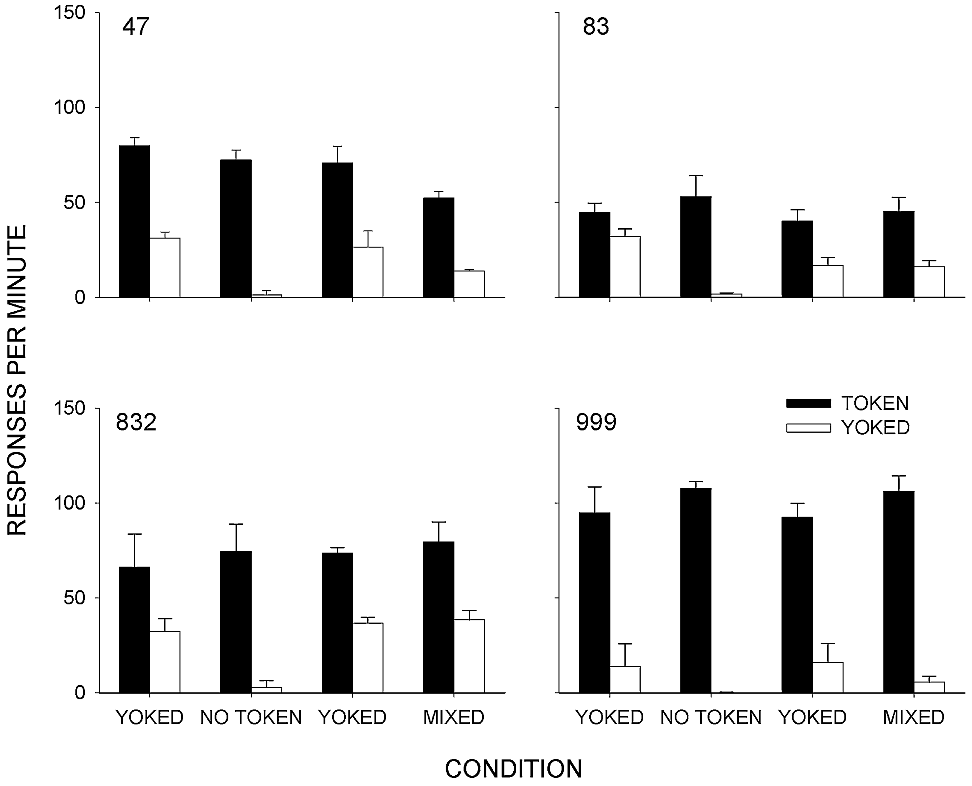

Fig. 6. Mean overall responses per min and standard deviations from the last five sessions of a condition for each pigeon in Experiment 3. Filled bars represent data from the token component whereas open bars represent data from the yoked component.

Discussion

Response rates in the yoked components were lower than in the token components, suggesting a role for the dependency between responding and token production (i.e., a reinforcing function). Although responding was lower in the yoked components, it was not altogether eliminated. Indeed, it continued to occur at moderate levels despite the absence of a response dependency. Only when the tokens were removed entirely was responding abolished. This suggests a role for stimulus–reinforcer relations (eliciting functions) apart from response–reinforcer relations (reinforcing functions).

Within a yoked-token component, response rates increased with temporal proximity to food in much the same way that they do under response-dependent token production. These findings are in accord with those reported by Ricci (1973) in a serial autoshaping procedure, in which the frequency of elicited keypecks increased across a sequence of key colors terminating in response-independent food delivery. Because the present study used a multiple schedule, one might argue that responding in the yoked component was due to induction from the standard component. If this were the case, however, one would expect rates in the two components to further converge in the mixed schedule, where the color of the response key was the same in the two components. This did not happen: In general, response rates during the yoked component under the mixed schedule were equal to or slightly lower than in the regular yoked components. These findings are inconsisent with an induction interpretation.

It may be possible to preserve an operant interpretation by pointing to the influence of adventitious response–consequence contiguities. There are two potential sources of

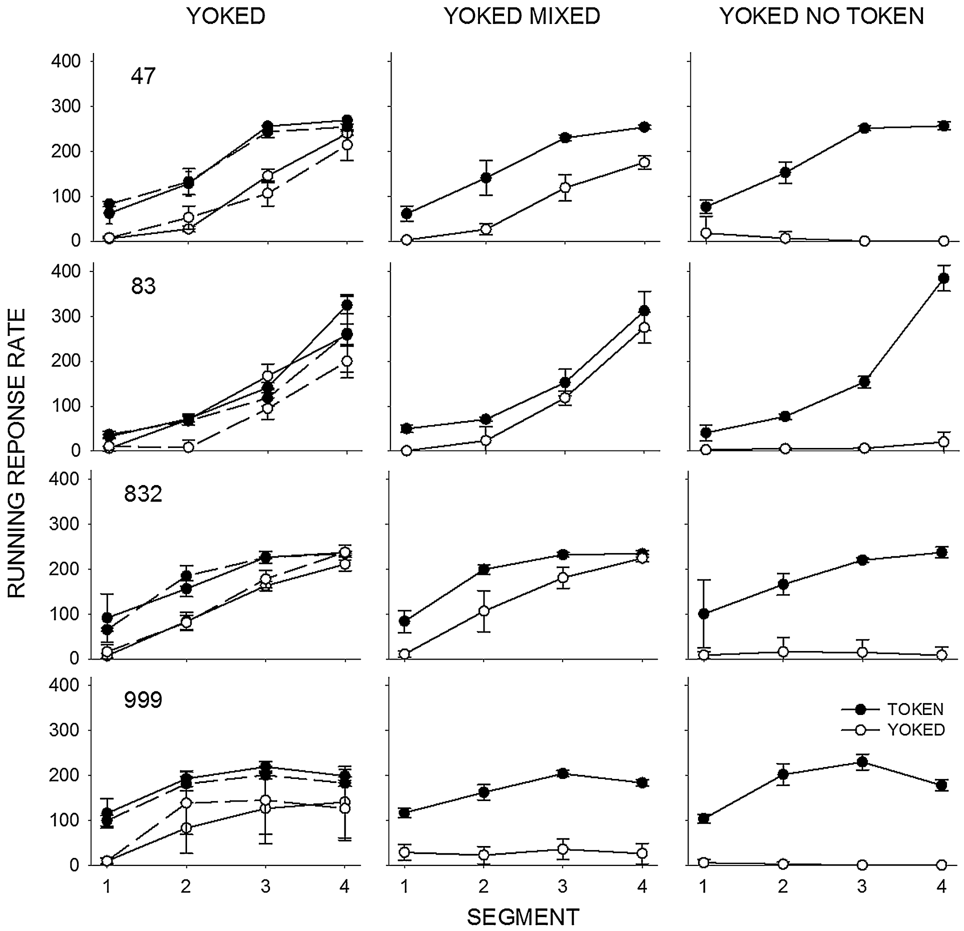

Fig. 7. Mean responses per min (excluding pre-ratio pause) plotted as a function of token production or yoked token-production segment from the last five sessions of each condition in Experiment 3. For no-token yoked components the segment data are organized around when the token would have occurred. Open symbols represent data from yoked components, closed from token components; solid lines represent original exposures, dashed lines replications.

adventitious contiguities in the present experiment: response–food contiguities and response–token contiguities. Zeiler (1968) showed that pigeons' key pecking was maintained, albeit at a lower rate, under schedules in which food reinforcers were delivered response-independently on fixed time (FT) and variable time (VT) schedules averaging 5 min. The no-token condition in the present experiment is essentially a type of VT schedule of food delivery (interfood intervals in the present experiment were in all cases shorter than 5 min). If adventitious reinforcement was responsible for the maintained responding under Yoked conditions in Experiment 3, one might expect responding to continue when the tokens were removed in *Yoked No-Token* conditions. The pigeons had prior experience responding in the absence of tokens in Experiment 1 (tandem component) and indeed response rates were higher without tokens than with them in Experiment 1. Removal of the tokens had the opposite effect in Experiment 3, however. If adventitious response–food contiguities were controlling performance in the yoked component in the present experiment one would expect more responding in the absence of tokens. On the other hand, if responses were elicited by the tokens in the yoked component, one would expect responding to cease when the tokens were removed.

Regarding response–token contiguities, the obtained response–token delays plotted in

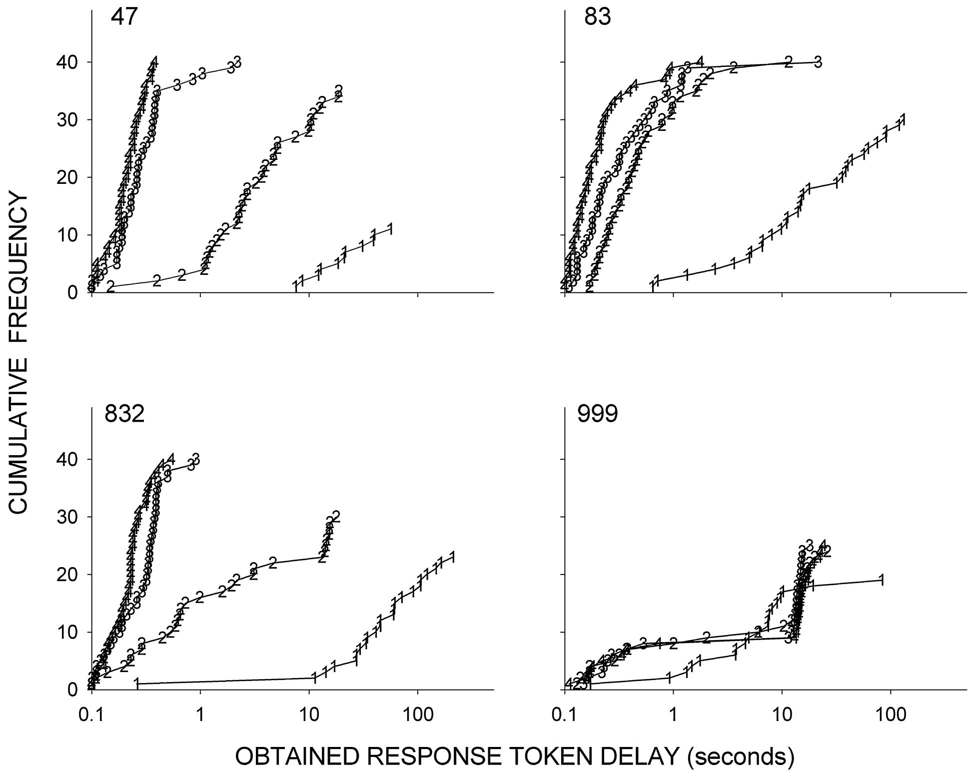

Fig. 8. Cumulative frequency of obtained response-token delays across token-production segments in the yoked components for each pigeon from the first condition in Experiment 3. The symbols correspond to the segment number within each exchange-production sequence.

Figure 8 suggest that adventitious contiguities might indeed account for responding under the yoked components. Prior research has shown that pigeons will continue to respond under conditions in which unsignaled obtained delays between pecking and reinforcement delivery reach upwards of 9 s (Schaal & Branch, 1988). For all subjects, obtained delays from the present yoked conditions were mostly within this range for the final three token production segments. However, viewed in light of other prior research with token-reinforcement schedules, the present findings depart from what one would expect if adventitious contiguities alone accounted for responding in the yoked components. Mazur & Biondi (2013) gave pigeons choices between concurrent VI 60 token production schedules, with exchange periods scheduled after a fixed number of tokens had been produced on either schedule. Pigeons preferred the absence of early tokens to their presence, suggesting an aversive function of tokens early in the sequence.

Given these results, one might expect that if responding were a function of adventitious response–token contiguity in the present study, the presence of tokens would decrease responding relative to their absence (particularly in the initial links). In Experiment 1 we found that for three pigeons response rates were lower in the second segment of a token schedule than under opposing tandem components. This suggests the potential for a discriminative function of the token from this segment akin to that found by Mazur & Biondi (2013). In Experiment 3, however, response rates in the second link were higher with tokens present (Yoked) than when absent (No Token) in seven of eight cases. Taken as a whole, these findings are difficult to reconcile with an account that appeals exclusively to adventitious reinforcement.

General Discussion

The objective of this series of experiments was to explore systematically the stimulus functions of tokens in token-reinforcement schedules. The research sought to situate token-reinforcement research within the broader context of extended sequence schedules, clarifying the role of added stimuli in temporally organized sequences of behavior. Performance under schedules of token reinforcement was compared to that under tandem schedules and to that under several token-like schedules, all with equivalent response requirements.

Experiment 1 compared token schedules to equivalent tandem schedules and it was found that response rates under token-reinforcement schedules were lower than under tandem schedules, with response patterning suggesting a discriminative function of the tokens. The temporal organization of behavior across successive response segments was consistent with that seen in prior research with token schedules (Foster et al., 2001; Bullock & Hackenberg, 2006), as well as other sequence schedules (Zimmerman & Ferster, 1964; Jwaideh, 1973).

Experiment 2 compared token schedules to extended chained schedules, and found that response rates under token-reinforcement schedules were lower than under comparable chained schedules when the correlation between token display and temporal proximity to exchange periods was altered. Only when compared to standard chained schedules, with a single reinforcer at the end of the chain, were response rates higher in token schedules, indicating sensitivity to reinforcement magnitude with stimulus conditions held constant.

Experiment 3 compared token schedules to schedules of response-independent token presentation to assess the operant (reinforcing) and nonoperant (eliciting) functions of the tokens. Response rates were reduced under the response-independent schedules, suggesting a reinforcing function, but not entirely eliminated, suggesting a nonoperant signaling function. Moreover, responding was temporally organized in relation to response-independent tokens in much the same way it was in relation to response-dependent tokens. These findings are consistent with those reported in the literature on serial autoshaping (Ricci, 1973), and suggest that the tokens may serve evocative/eliciting functions in addition to operant functions.

Taken together, the results of the present experiments suggest that tokens serve multiple stimulus functions in token-reinforcement schedules, and that the specific function, or functions, depend on the contingencies in which they are embedded. In the context of a three-term (operant) contingency, the tokens serve a reinforcing function for responses that produce them and a discriminative function for responses occasioned by them. In the context of a two-term (Pavlovian) contingency, the tokens serve a conditional-stimulus (CS) function, eliciting behavior on the pattern of a reflex. To identify one stimulus function is not to deny the *potential* importance of other functions, as those functions may very well be present under different conditions. The precise function, or functions, of the tokens is not intrinsic to the stimulus; it is in a very real sense actualized—literally brought into existence—by the contingencies.

As stimuli embedded in a larger set of contingencies, tokens unquestionably serve multiple, and often overlapping, functions. This is not unique to token systems. The multiple functions of stimuli in chaining and temporal organization date back to Skinner's earliest work (Skinner, 1938), and, more recently, such multiple functions have emerged as an implicit organizing principle in the domains of conditioned reinforcement(Williams, 1994; Shahan, 2010) and negative reinforcement (Hineline, 1981; DeFulio & Hackenberg, 2007). Such multiple functions may well be inevitable in any complex behavioral system. As in these other areas of research and theory, it may be more profitable here in the context of token schedules to ask not *which* function a stimulus serves, but rather, *under what conditions* one function or another will come to predominate.

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