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GENERALIZED CONDITIONED REINFORCEMENT WITH PIGEONS IN A TOKEN ECONOMY

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Six pigeons were studied in a token economy in which tokens could be produced and exchanged for food on one side of an experimental chamber and for water on the opposite side of the chamber. Responses on one key produced tokens according to a token-production fixed ratio (FR) schedule. Responses on a second key produced an exchange period during which tokens were exchanged for water or food. In Experiment 1a, food tokens could be earned and exchanged under restricted food budgets, and water tokens could be earned and exchanged under water restricted budgets. In Experiment 1b, a third (generalized) token type could be earned and exchanged for either food or water under water restricted budgets. Across Experiments 1a and 1b, the number of tokens accumulated prior to exchange increased as the exchange-production schedule was increased. In Experiment 1b, pigeons produced more generalized than specific tokens, suggesting enhanced reinforcing efficacy of generalized tokens. In Experiment 2, the FR token-production price was manipulated under water restriction and then under food restriction. Production of each token type generally declined as a function of its own price and increased as a function of the price of the alternate type, demonstrating own-price and cross-price elasticity. Production of food and water tokens often changed together, indicating complementarity. Production of specific and generalized tokens changed in opposite directions, indicating substitutability. This is the first demonstration of sustained generalized functions of tokens in nonhumans, and illustrates a promising method for exploring economic contingencies in a controlled environment.
Key words: behavioral economics, water reinforcers, elasticity, pigeons, token reinforcement

The concept of conditioned reinforcement—how initially neutral events acquire and maintain reinforcing functions—is central to a comprehensive account of behavior. There is a vast literature on the topic of conditioned reinforcement dating back to the 1930s and extending through to the present (see reviews by Fantino, 1977; Kelleher & Gollub, 1962; Shahan, 2010; Williams, 1994), and conditioned reinforcement occupies an important place in many extensions to everyday human behavior. The laboratory analysis of conditioned reinforcement has employed a host of methods over the years—including discrete-trial procedures, free-operant acquisition and extinction procedures, observing procedures, choice procedures, and token economy procedures—with a variety of species—including rats, pigeons, monkeys, chimpanzees, and humans.

In spite of this methodological diversity, one aspect of the laboratory analysis of conditioned reinforcement has remained fairly constant: Nearly all of the work with nonhuman subjects has involved specific conditioned reinforcers (established and maintained as such through pairing with a single unconditioned reinforcer such as food or water), whereas most of the work with human subjects has involved generalized reinforcers (established and maintained via their relation to two or more sources of reinforcement). These latter reinforcers are generalized in the sense that their reinforcing function is not tied to a specific deprivation. As Skinner (1953) long ago noted, generalized reinforcers should be stronger and more durable than specific-type reinforcers because some relevant source of deprivation is more likely to prevail at the time of reinforcement (i.e., when the conditioned reinforcers are

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exchanged for other reinforcers). While this assertion is plausible, the empirical evidence of generalized reinforcement is surprisingly scant.

The paucity of research on generalized reinforcement is at odds with its explanatory potential in everyday human life. In addition to its obvious relevance to the analysis of money as a reinforcer, the widespread use and success of educational and therapeutic applications of the token economy testifies to the importance of generalized reinforcement in applied settings. Despite their ubiquity and clinical utility, little is known about how generalized reinforcers work – the kinds of experiences needed to establish them as reinforcers, the kinds of contexts needed to maintain them, and the kinds of deprivations needed to sustain them.

The few empirical studies on the topic have produced weak and transient effects (Myers & Trapold, 1966; Nevin, 1966). The problem seems likely due to the fact that the putative generalized reinforcer in these studies was a briefly presented stimulus, not present at the time of reinforcement. A promising alternative approach to the problem involves token reinforcement procedures, with which it is possible to maintain consistent pairings between conditioned and unconditioned reinforcers. In an early experiment along these lines, Wolfe (1936) gave chimpanzees repeated choices between yellow poker chips (exchangeable for water) and black poker chips (exchangeable for peanuts) under 16-hr food or water deprivation. The deprivation conditions alternated every two days. All three subjects generally preferred the tokens appropriate to the current deprivation conditions; or, as Wolfe put it, the chimpanzees' choices were "in harmony with natural drives." Even stronger effects were found for other subjects under 24-hr deprivation conditions that also included prefeeding on the alternate reinforcer. Had Wolfe paired a third token type with both water and peanuts, he would have been in a position to examine generalized reinforcing functions of tokens. Of the dozens of subsequent laboratory studies of token reinforcement, none to date have taken up the problem of generalized reinforcement (see review by Hackenberg, 2009).

The present study represents an initial attempt toward the investigation of generalized reinforcement, using a laboratory-based token reinforcement system. The procedures are patterned after those used in recent research with pigeons in token-based reinforcement procedures with stimulus lamps as tokens (e.g., Bullock & Hackenberg, 2006; Lagorio & Hackenberg, 2010, 2012; Raiff, Bullock, & Hackenberg, 2008). More specifically, we used a type of token-accumulation procedure described by Yankelevitz, Bullock, and Hackenberg (2008). In this procedure, responses produced tokens according to one schedule of reinforcement (hereafter, the *token-production schedule*). Once the first token had been earned, a second option became available: production of an exchange period, during which all tokens earned to that point could be exchanged for food. Responses on this second option were reinforced according to an independent schedule of reinforcement (hereafter, the *exchange-production schedule*). Yankelevitz et al. manipulated the token-production and exchange-production schedules and found that both were important determinants of token accumulation. As the exchange-production schedule was increased, pigeons accumulated more tokens before entering periods of food exchange. In contrast, greater token production requirements resulted in lower levels of token accumulation.

In the present study, we manipulated the price of producing and exchanging specific and generalized tokens with pigeons under two distinct types of deprivation: food and water. Green tokens were exchangeable on one side of the experimental chamber for food, whereas red tokens were exchangeable on the other side for water. In Experiment 1a, we replicated the Yankelevitz et al. (2008) exchange-production manipulations using food or water reinforcers under conditions of food or water deprivation, respectively. The goal was to establish specific reinforcing functions of two separate tokens, each under the control of a matched deprivation condition, in much the same way that Wolfe (1936) had done with chimpanzees.

In Experiment 1b, we added a third token type—a white token—that could be exchanged for either food or water. Under water deprivation, pigeons could produce (a) food tokens, exchangeable only for food, (b) water tokens, exchangeable only for water, or (c) generalized tokens, exchangeable for either food or water. The exchange-production ratio was manipulated across conditions, while the token-production ratio (price) was held constant. The objective was to assess the relative reinforcing value of the generalized tokens in preference tests against specific food and water tokens. If the reinforcing value of the generalized tokens was enhanced by virtue of its pairing with multiple reinforcers, one would expect preference for the generalized over the specific tokens when available at the same price.

Relative preferences for generalized and specific tokens were examined further in Experiment 2. Token-production prices were selectively manipulated across conditions under both water and food restriction. The objectives were twofold: The first was to assess preferences for the different token types as their prices were systematically altered across conditions. The second was to evaluate interactions between different token types by measuring production and consumption of same-priced tokens in the context of price changes of alternate tokens. Two types of reinforcer interaction were of interest: (a) *substitutability*—enhanced demand for one reinforcer with price increases for an alternate reinforcer; and (b) *complementarity*—reduced demand for one reinforcer with price increases for an alternate reinforcer. The former is of interest to generalized functions, as generalized reinforcers are defined in part by the degree to which they functionally substitute for other reinforcers. The latter is of interest because prior research has shown food and water to be complementary reinforcers (Hursh, 1978).

Exploring these relations under both food and water restriction enables a further test of specific and generalized functions of the tokens and the degree to which they depend on background motivational contexts. These different contexts should alter the relative value of the different token types. Water tokens and food tokens should be produced selectively in water and food deprivation contexts, respectively. Generalized tokens, however, should be produced in both contexts, but exchanged for different reinforcers, depending on the deprivation condition. Together, the experiments provide a novel experimental context for assessing preference and demand across economic and motivational conditions that should provide important insights into the relative reinforcing value of the generalized and specific tokens. The layout of all parts and phases of these experiments is shown in Table 1.

Experiment 1

Method

Subjects. All subjects were adult male White Carneau pigeons (*Columba livia*). Four pigeons (designated 2902, 999, 723, and 271) served as subjects in Experiment 1a; these pigeons had various histories with token reinforcement procedures. Two additional pigeons (22 and 113), experimentally naïve, were added for Experiment 1b. All pigeons were housed in individual cages in a colony room and had free access to grit. During experimental conditions in which tokens were exchangeable for water (hereafter *Water* conditions), pigeons were maintained at unrestricted weight and had free access to mixed grain while in the colony room. During experimental conditions in which tokens were exchangeable for food (*Food* conditions), pigeons were maintained at 83% of their free-feeding body weight and had free access to water while in the colony room. The colony was kept on a light/dark cycle with a light duration of 16.5 hours beginning at 0700.

Apparatus. The experiment was conducted in an operant chamber with two intelligence panels on opposing sides. The panels were

Table 1

Outline of Experiments

Exp	Part	Phase	Deprivation	Tokens*	Independent Variable	Order
1A	1		Water	W	Exchange Production Schedule	1
	2		Food	F	Exchange Production Schedule	2
1B			Water	W, F, G	Exchange Production Schedule	5
2	1	1	Water	W, F, G	Generalized Token Production Schedule	3
		2	Water	W, F, G	Specific Token Production Schedule	4
	2	1	Food	W, F, G	Generalized Token Production Schedule	6
		2	Food	W, F, G	Specific Token Production Schedule	7

*- (W)ater, (F)ood, (G)eneralized

spaced 50 cm apart, and measured 35 cm long and 39 cm high. A solenoid-operated food hopper was used to deliver 3-s access to mixed grain through one of the panels (hereafter, the food panel), accompanied by a white hopper light. On the other panel (hereafter, the water panel) a Med Associates, Inc. PHM-100VS Variable Rate Infusion Pump delivered water from a large syringe through a tube attached to the underside of a small round transparent plastic cup, 2.5 cm diameter with a 10 mL capacity. Water deliveries consisted of 2.5 s of pump activation yielding 0.8 ml water. During pump activation a white light below the cup was illuminated. Both panels were equipped with three translucent response keys, 2.5 cm in diameter, located 21.5 cm from the floor, and spaced 6 cm apart. Side keys on the food panel could be illuminated red (Experiment 1a) or red and white (Experiment 1b), and on the water panel could be illuminated green (Experiment 1a) or green and white (Experiment 1b). The center (exchange) keys could be illuminated red, blue or yellow. A force of 0.12 N was required to register a response on the keys, and a software filter used throughout all training and experimental sessions prevented responses with interresponse times of less than 50 ms from being counted. Houselights provided general illumination, and were mounted 4 cm from the ceiling. Houselights and center response keys were centered horizontally on the panels. For each panel, the houselight was illuminated whenever at least one response key on that panel was active. Each panel included a token array consisting of 12 token lights. These lights measured 2 cm in diameter and were distributed evenly across the horizontal plane beginning 3 cm from the edges of the panel and located 7.5 cm from the ceiling. Red token lights were mounted on the water panel, green token lights on the food panel, and white token lights on both panels (Experiment 1b). Tokens were produced (turned on) from left-to-right and exchanged (turned off) from right-to-left. All experimental events were controlled and data collected by a PC using MED-PC IV software and located in an adjacent room.

Procedure for Experiment 1a. This experiment had two parts. The first, Part 1, was conducted under water deprivation, and was designed to establish the red tokens as conditioned reinforcers by pairing them repeatedly with water; the second, Part 2, was conducted under food deprivation, and was designed to establish the green tokens as conditioned reinforcers by pairing them repeatedly with food. In both parts of the experiment, a session was composed of a series of cycles, beginning with the presentation of the left (token-production) key. In Part 1, the token-production key was red and was situated on the water panel of the chamber; in Part 2, the key was green and was situated on the food panel. Each peck on the token-production key produced a 0.1-s tone and illuminated the leftmost unlit token, up to a maximum of 12. When 12 tokens had been produced, the token-production key remained lit, but responses on it had no programmed consequences. When the first token of each cycle had been produced, the center (exchange-production) key was illuminated blue, signaling the availability of exchange production. The token-production and exchange-production schedules were independent (i.e., pecks on one key had no effect on the contingencies or response requirements on the other key) and concurrently available, providing a choice between earning additional tokens and producing an exchange period during which red tokens could be exchanged for water (Part 1) and green tokens for food (Part 2). Satisfying the exchange-production ratio requirement turned off the center key and changed the left key from red (or green) to yellow, signaling the beginning of an exchange period. During an exchange period each peck on the left yellow key turned off a token and produced either 0.8 mL of water (Part 1) or 3-s access to food (Part 2). Exchange periods remained in effect until all tokens were exchanged. When all tokens were exchanged, a new cycle began with the illumination of the token-production key. Thus, a cycle consisted of token production, exchange production, and exchange.

Sessions were conducted 7 days per week at approximately the same time each day. Sessions ended after 75 min or after a criterion number of reinforcer deliveries, whichever came first. The criterion number of reinforcer deliveries for session termination was 30 for water (Part 1) or 40 for food (Part 2). In order to insure that all earned tokens could be exchanged, the reinforcer delivery criterion for session termination was evaluated only at the conclusion of exchange periods. Because of this, and because the number of tokens per exchange could vary from 1–12, the maximum obtained number of

Table 2

Order of conditions and number of sessions per condition for Experiment 1a.

		Pigeon			
Part	Condition	723	999	2902	271
1	FR1	21[a]	23[a]	22[a]	33
	FR25	33[a]	59[a]	14[a]	28
	FR50	30[a]	90[a]	21[a]	52
	FR100	69[a]	21[a]	24[a]	19
	FR50	26[a]	22[a]	–	–
	FR50	–	20	–	–
	FR50 NT	47[a]	34	–	–
	FR50 NT	24	–	–	–
	FR100 NT	24	–	49	30
	FR100 NT	–	–	57	-
	FR50	–	–	–	14
	FR100	42	–	–	–
2	FR1	14	15	15	41
	FR25	14	60	26	23
	FR50	47	21	-	20
	FR100	78	37	54	31
	FR25	19	–	–	–

[a]conditions conducted in an open economy.
Note. Condition labels indicate exchange-production FR value. NT indicates *No-Token* conditions in which tokens were not illuminated.

water deliveries per session was 41 (Part 1) and the maximum number of food deliveries was 51 (Part 2).

In both parts of Experiment 1a, the exchange-production FR was manipulated across conditions in an ascending sequence, from FR 1 to FR 100. Table 2 shows the sequence of conditions and the number of sessions conducted in each, across the two parts of Experiment 1a. Conditions lasted for a minimum of 14 sessions and until stability criteria were met. Stability criteria required that no trend was apparent by visual inspection, and that neither the highest nor lowest values for mean tokens accumulated per exchange occurred in the last five completed sessions, with exceptions for floor and ceiling effects due to exclusive or near-exclusive preferences. Replications were conducted in both parts of the experiment. *No-Token* control conditions, conducted in the water-restriction conditions, were identical to typical sessions with the exception that the token lights were never turned on; thus a brief tone was the only signal that a token had been earned.

In Part 1, under water deprivation, sessions were not always completed. A session was considered incomplete if fewer than 20 water deliveries were delivered during the session, and these sessions were discarded from the analysis. Such incomplete sessions occurred more frequently in the training and early conditions in the sequence, conducted in an *open economy*, in which the pigeons received 5-min free access to postsession water. This was accomplished by drilling a hole in the bottom of the water trough such that a full trough was drained by the end of 5 min, and filling this trough at the home cage immediately after session completion. Over the course of the first several months of the experiment, however, incomplete sessions occurred with increasing frequency for three pigeons (723, 999, 2902). To enhance responding, conditions were changed to a *closed economy* in which daily intake (24 mL) of water occurred within the sessions, with all other experimental parameters held constant. The pigeons completed all sessions in the closed economy, and these conditions therefore remained in place, and became part of the standard water reinforcement context in the later experiments. Pigeon 271 was studied only in the closed economy. In the rare sessions in which less than 10 mL water was earned, 10 mL supplementary water was provided immediately following the session. Over the many months of the experiment (226 daily sessions, on average, in Part 1), we observed no ill effects of the water-restriction methods; the pigeons were healthy and responded well to the procedures.

Preliminary training for water reinforcement. Before the red tokens could be paired with water reinforcers in Part 1, water had to be established as an effective reinforcer in its own right. Several training steps were undertaken to induce pigeons to drink reliably, first in their home cages and next in the chamber. Because there is little published research with water reinforcers and pigeons, we provide here a fairly detailed description of our preliminary training protocol.

The pigeons were first trained to drink in their home cages from the cup later used in experimental sessions, and had free access to grit and mixed grain throughout the day. Free access to water was restricted to one 5-min period each day. Water was initially presented in a standard 227 g metal measuring cup with the handle bent to hook onto the cage. Every three days the cup size was reduced by half until the cup size measured 28.4 g. The standard measuring cup was then replaced with an identically sized metal measuring cup fitted with a smaller cup inside. This smaller cup was identical to the cup in the experimental chamber. After three days of drinking from this cup, magazine training began in the experimental chamber, which began with continuous illumination of the light under the water cup, which was filled with 0.8 mL of water. After the first time the water was consumed, the light was dimmed for 3-s then reilluminated simultaneously with a 0.8 mL delivery of water into the cup. This process continued under direct observation throughout the session, which consisted of 30 water deliveries. All pigeons drank readily from the cup in the experimental chamber after a single session. The pigeons were then trained with contingent water access by the method of successive approximations to peck the red center key on the water panel. This was followed by several sessions designed to establish the exchange response, in which the red center key and leftmost token were illuminated. During these sessions, each peck on the red center key initiated a token exchange—a stimulus complex consisting of a 0.1-s tone, a 0.8 mL (2.5-s) water delivery, and turning off the token, center key, and houselight. The light under the water cup remained illuminated for 1.5 s after each water delivery, after which a new cycle began immediately with the illumination of the center key, the token, and the houselight. Once the exchange response had been established, a backward-chaining procedure was used to establish pecking on the left (token-production) key. These sessions began with left key illuminated red—pecks on which produced a 0.1-s tone, illuminated both a token and the blue center (exchange) key, and turned off the left key. A peck on the blue center (exchange production) key changed the key color from blue to red, signaling the beginning of an exchange period. A peck on the red center (exchange) key initiated a water reinforcement cycle, consisting of a water delivery, a 0.1-s tone, 0.5-s illumination of the water cup, and turning off the token light, center key, and houselight. When pigeons had completed at least 21 sessions under these conditions, the experiment proper began.

No preliminary training was needed for Part 2, as the pigeons had prior experience pecking keys for food reinforcers. A transition period occurred between Parts 1 and 2 to switch from water deprivation to food deprivation, during which no experimental sessions were conducted. Pigeons had free access to grit and water, and were fed 9 g of mixed grain per day at approximately the same time that experimental sessions were conducted. This transition period lasted an average of 18 days. Conditions with tokens exchangeable for food began when each pigeon's body weight reached approximately 83% of its free-feeding body weight.

Procedure for Experiment 1b. Experiment 1b was conducted under water restriction conditions, as in Part 1 of Experiment 1a. The two pigeons new to Experiment 1b (22 and 113) were exposed to a training history like that of Experiment 1a, but in a truncated fashion. Prior to the experiment proper, all six pigeons were given free access to grit and mixed grain and 30 ml of water per day over a period of 10 days at approximately the same time of day that sessions were conducted. The pigeons then underwent a series of training conditions, described in more detail in the section on preliminary training for two-panel sessions below.

Terminal procedure. In the terminal procedure, two components—those in which token production occurred on the water panel (*Water* components) and those in which token production occurred on the food panel (*Food* components)—were presented successively in a MULT schedule. In *Water* components, pigeons could earn up to six red tokens. These were the leftmost six tokens in the token array on the water panel. In *Food* components, pigeons could earn up to six green tokens. These were the leftmost six tokens in the token array on the food panel. In addition to the specific (red and green) tokens, each panel had six white tokens, positioned as the rightmost six tokens in the respective token arrays on both panels. These tokens could be produced on either panel, and when produced were signaled by the illumination of the leftmost unlit white token on both panels. White tokens could be exchanged for either food or water. Exchange responses of any type, specific or generalized, occurred on the respective key—red key for water tokens, green key for food tokens, and either of the white keys for generalized tokens—and were signaled by flashing the respective key light (0.2 s on, 0.2 s off). Exchange responses on the food panel produced food whereas exchange responses on the water panel produced water; white token exchanges on either side removed one token from *both* panels; the number of white tokens on each panel was therefore always the same. Although it was possible to earn up to 12 tokens per cycle (6 specific and 6 generalized), no pigeon produced more than one token type per cycle, effectively limiting the maximum number of tokens per cycle to six. *Food* and *Water* components were selected in a pseudorandom fashion, such that each component was active in two of the four components comprising a session. Table 3 shows the sequence of conditions and the number of sessions conducted in Experiment 1b.

The exchange-production ratio was systematically varied across conditions, from FR 1 to FR 150 (250 for Pigeon 113). An intermediate exchange-production ratio (FR 50) was replicated for four of six pigeons. As in Experiment 1a, sessions were terminated at the end of the exchange period in which the 30th water delivery occurred, or after 75 min, whichever came first. Sessions with less than 20 water deliveries were excluded from analysis, but this was a very rare occurrence. Supplementary water (10 mL) was provided in the rare session in which less than 10 mL water was earned. Conditions were considered complete when a minimum of 14 sessions had been conducted and no trend was apparent in the total number of (green, red, and white) tokens earned and total number of (food and water) exchanges produced across the last nine sessions, when plotted as three-session means. Order of conditions and number of sessions per condition for Experiment 2 are shown in Table 4.

Preliminary training for two-panel sessions. A sequence of four training conditions was followed with each pigeon, lasting about 48 sessions, on average. Because the training procedures were somewhat novel, they will be described in detail. In the first condition, the pigeons were trained to produce white tokens by pecking the white token-production key on both the *Food* and *Water* panels, and exchange them for water. At the beginning of each cycle, one of the panels was chosen as the location for token production: This selection was made pseudorandomly, such that each panel was selected three times across the six-cycle session. The right (white) key and houselight on the chosen panel were illuminated at the beginning of a cycle. When token production occurred on the food panel, the houselight and center (blue) key on

Table 3

Order of conditions and number of sessions per condition for Experiment 1b.

	Pigeon					
Condition	113	22	723	999	2902	271
FR1	16	16	26	15	21	13
FR25	41	22	21	49	62	38
FR50	36	74	21	16	30	57
FR100	25	20	25	24	43	47
FR150	42	27	31	18	26	18
FR200	16	–	–	–	–	–
FR250	26	–	–	–	–	–
FR100	20	–	–	–	–	–
FR50	–	14	39	46	–	–

Note. Condition labels show exchange schedule requirement.

Table 4

Order of conditions and number of sessions per condition for Experiment 2.

			Pigeon					
Part	Phase	Condition	113	22	723	999	2902	271
1	1	GFR1/SFR1	–	30	17	24	23	23
		GFR10/SFR1	32	15	60	36	59	36
		GFR25/SFR1	10	19	14	29	35	23
	2	GFR1/SFR1	16	14	51	18	32	21
		GFR1/SFR10	18	14	36	17	24	17
		GFR1/SFR25	25	23	18	14	34	14
		GFR1/SFR1	–	18	–	108	–	15
		GFR1/SFR10	16	–	–	–	–	–
	1	GFR1/SFR1	21	–	–	–	–	–
		GFR10/SFR1	23	–	–	–	–	30
		GFR25/SFR1	–	–	–	–	20	–
		GFR1/SFR1	–	–	–	–	–	60
2	1	GFR1/SFR1	39	–	14	17	12	17
		GFR10/SFR1	11	–	16	17	12	10
		GFR25/SFR1	31	–	11	14	18	12
		GFR50/SFR1	29	–	52	30	42	11
		GFR100/SFR1	23	–	15	26	24	60
		GFR25/SFR1	22	–	28	17	21	34
	2	GFR1/SFR1	28	–	16	28	14	34
		GFR1/SFR10	15	–	14	14	14	14
		GFR1/SFR25	20	–	11	19	15	11
		GFR1/SFR10	20	–	14	15	17	15
		GFR1/SFR1	21	–	28	48	23	20

Note. Condition labels indicate token production schedules for generalized (GFR) and specific (SFR) token production schedules.

the water panel were illuminated after the first response on the white token-production key. In these cases, pigeons were required to walk across the chamber to complete the exchange-production schedule requirement on the blue center key of the water panel. When token production occurred on the water panel, the response keys on the food panel were inactive for the entire cycle.

When pigeons readily walked from one side of the chamber to the other to produce and exchange tokens, they progressed to the second step of training, in which the white tokens were exchanged for either food or water. When the first token was produced, one of the panels was chosen as the location for exchange production and exchange; the selection was pseudorandom such that each panel was selected three times across six cycles. Thus, within a given session, tokens could be (a) produced and exchanged on the *Water* panel, (b) produced and exchanged on the *Food* panel, (c) produced on the *Water* panel but exchanged on the *Food* panel, or (d) produced on the *Food* panel but exchanged on the *Water* panel. Exchange production on the *Food* panel occurred on the center yellow key, and exchange production on the water panel occurred on the center blue key. Exchange occurred on the right white flashing key on both panels (as described above).

When pigeons readily completed all four kinds of cycles, they progressed to the third step of training, in which the left keys (red and green on the water and food panels, respectively) on both panels were reintroduced, as were the six leftmost tokens (also red and green on the water and food panels, respectively). Only one of the four possible token-production (side) keys was activated for a given cycle, and the selection was again quasirandom, such that each of the four possibilities occurred once every four cycles. When one of the left keys was activated, the (red or green) tokens were earned and exchanged on the same panel. Thus, a peck on the left red key on the water panel produced a red token exchangeable exclusively for water, and a peck on the left green key on the food panel produced a green token exchangeable exclusively for food. These specific-token exchanges occurred on the left keys of each panel, with the response key flashing red (water panel) or green (food panel; in both cases 0.2 s on and 0.2 s off). When one of the right keys was activated, white tokens were earned on one panel, and exchanged on either the same or opposite panel with equal probability. Thus, a peck on an activated right white key produced a white token on both panels that was exchangeable for either food or water, with the selection again pseudorandom. For all of these scenarios, an exchange-production center (blue or yellow) key was illuminated after the first token was produced. In any given cycle, exchange production was only available on the panel for which exchange was programmed.

When pigeons readily completed all six (one red token, one green token, and four white token) types of cycles, they progressed to the fourth and final step of training, in which production of a white token produced both blue and yellow center (exchange-production) keys on each panel. When the exchange-production requirement was satisfied on a given panel, exchange was produced on that same panel. Thus, pigeons were able to choose whether white tokens were exchanged for food or water, with the lone constraint that all white tokens earned in a given cycle were only exchangeable for a single commodity. This change yielded four types of cycles: (a) red (water) token production, (b) green (food) token production, (c) white (food or water) token production on the water panel, and (d) white (food or water) token production on the food panel. When pigeons readily completed all four kinds of cycles they progressed to the terminal procedure as described above.

Results and Discussion

Figure 1 shows the mean (and standard deviation) number of tokens accumulated per cycle across conditions for each pigeon in both parts of Experiment 1a. In general,

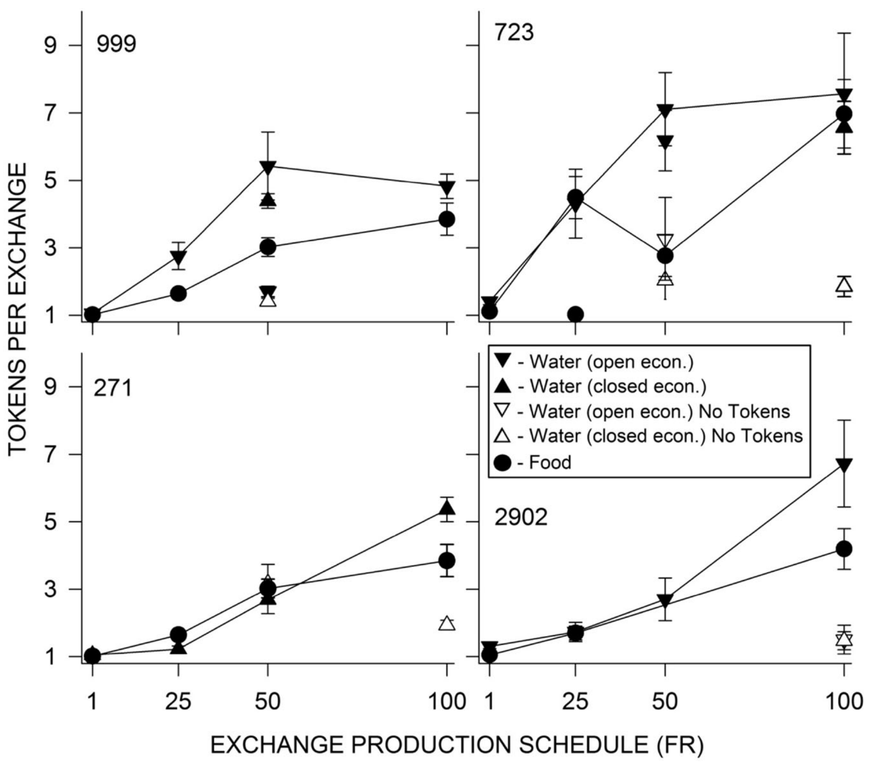

Fig. 1. Mean tokens accumulated per exchange cycle as a function of exchange-production FR schedule requirement with water-specific tokens under water deprivation (triangles) and food-specific tokens under food deprivation (circles) in Experiment 1a. Disconnected open points show means from No-Token conditions. Disconnected filled points show means from replication conditions. Error bars show standard deviations.

accumulation increased as the exchange-production FR was increased. This relation held across conditions, whether tokens were exchangeable for water (Part 1) or for food (Part 2). In Part 1, conditions conducted in a closed and open economy did not produce discernibly different effects on mean tokens per exchange, although closed economy sessions resulted in more consistent performance (less session-to-session variability and fewer sessions missed). Substantially less accumulation occurred under *No-Token* conditions than under comparable conditions in which tokens were illuminated. This was true across closed and open economy conditions in Part 1 (cf. Pigeon 723 [FR 50] and 2902 [FR 100]).

Both of these effects—the increasing accumulation as a function of the exchange-production FR, and the lower levels of accumulation when tokens were removed—are consistent with previous results with food reinforcers (Yankelevitz et al., 2008). The systematic results obtained under both reinforcer types suggest the utility of the present token-accumulation procedures, and the general comparability of results obtained with food and water reinforcers suggests that the nature of the reinforcer is less important than the nature of the contingencies. The large differences between accumulation in the presence and absence of tokens confirm the importance of this variable, reported in other studies (Lagorio & Hackenberg, 2010, 2012; Yankelevitz et al., 2008).

Figure 2 shows mean (and standard deviation) number of tokens per cycle as a function of exchange-production FR schedule in Experiment 1b. The total of all tokens earned (food, water, and general) was divided by the number of exchanges across the last nine sessions of each condition. Accumulation increased systematically as the exchange-production schedule requirement increased, similar to that seen with specific food or specific water tokens (Fig. 1). The figure also shows accumulation by token type. The majority of tokens accumulated and later exchanged were either water tokens or generalized tokens; when a generalized token was produced in either component, it was nearly always exchanged for water (92% across subjects, range = 76–99%). Accumulation of these two token types increased with exchange-production ratio in a majority of cases, largely paralleling the mean function. In two cases (999 and 2902), food tokens were also consistently accumulated, despite free access to food outside the sessions. In both cases, the functions relating food tokens to exchange ratio were accompanied by parallel functions relating water (2902) or generalized (999) tokens to exchange ratio. This parallel increase in food and water-related tokens suggests a complementarity relation between food and water commodities (Hursh, 1978).

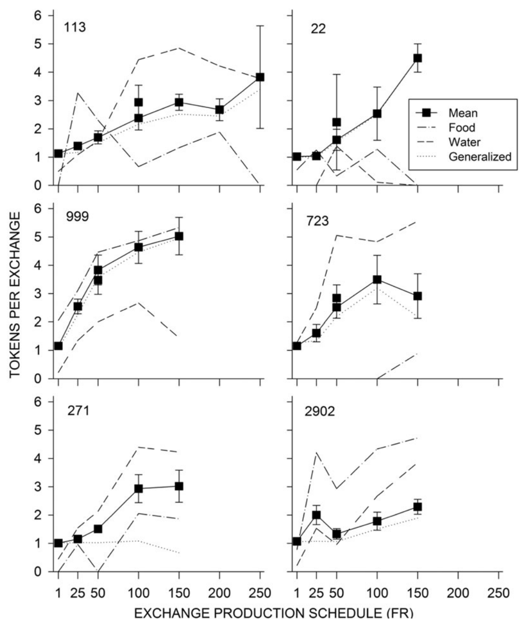

Fig. 2. Mean tokens accumulated per exchange cycle as a function of exchange-production FR schedule requirement in Experiment 1b. Broken functions show accumulation of each token type. Disconnected open points show means from replication conditions. Error bars show standard deviations.

Figure 3 shows the number of specific and generalized tokens produced per session in *Food* and *Water* components as a function of exchange-production ratio across the final nine sessions of each condition. In the *Food* components (left panels), all six pigeons produced more generalized than specific tokens in a majority (23 of 30) of conditions, with a 2.05:1 ratio of generalized to specific tokens combined across all subjects and conditions. This pattern of token production and exchange was an extended sequence of behavior that began on one side of the chamber (producing white tokens on the food panel) and ended on the other (exchanging the white tokens for water on the opposite panel), suggesting a clear

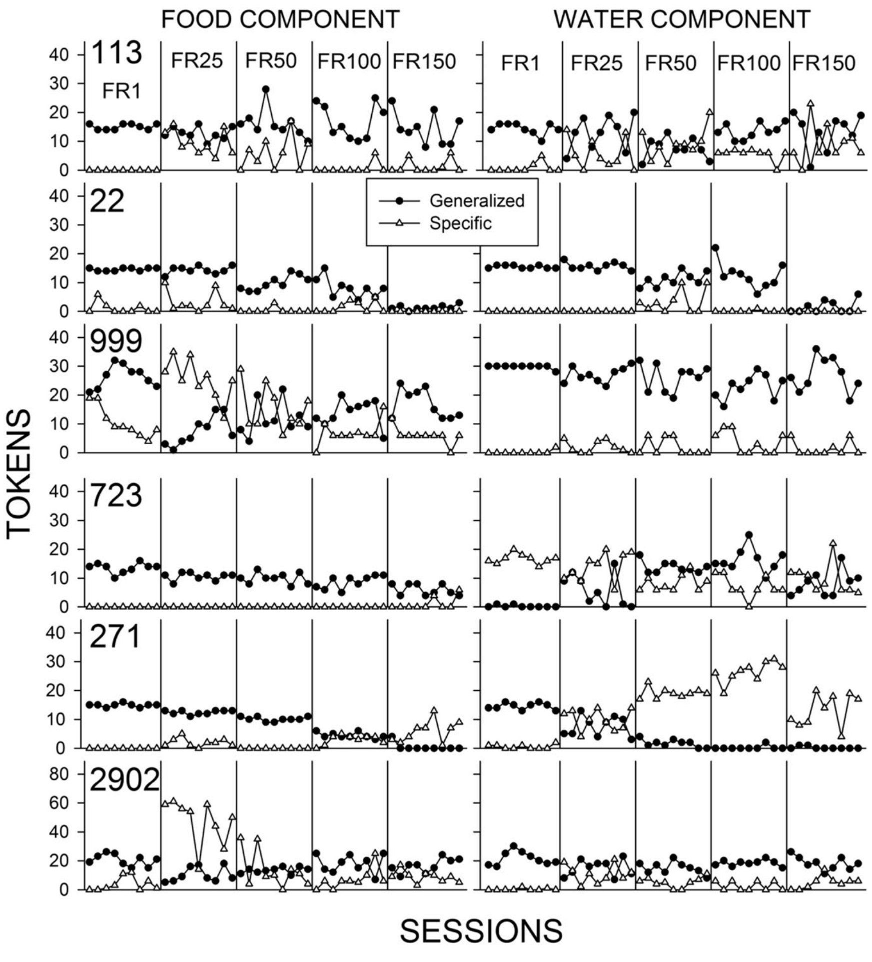

Fig. 3. Mean tokens per session earned on each generalized and specific token production keys during the last nine sessions of each condition in Experiment 1b. The left panels show tokens earned in food components and the right panels show tokens earned in water components. To enhance the economy and clarity of display, conditions FR 200 and FR 250 for pigeon 113 are not shown. Across the last nine sessions of these two conditions, 113 produced 89.2% and 100% generalized tokens during the food component, respectively, and 77.6% and 53.4% generalized tokens during the water component, respectively.

sensitivity to the generalized functions of the white tokens. That such generalized tokens were earned consistently in the *Food* component (and subsequently exchanged for water) is perhaps not surprising, given that water was restricted outside the sessions. Such a pattern enabled water consumption in both components, and thus may say less about the reinforcing efficacy of the generalized tokens than about their participation in a chain of responses that resulted in water. Figure 4 illustrates this point further, showing that generalized tokens were typically exchanged for water across all conditions and for all pigeons in Experiment 1B.

More direct evidence of generalized functions comes from the distribution of specific and generalized tokens in the *Water* components (right panels of Fig. 3). One pigeon (723) showed an initial preference for specific water tokens that weakened over time, and another (271) showed a strong preference for specific tokens after an initial preference for general tokens. The other four pigeons tended to prefer the generalized to the water tokens (18 of 22 conditions), despite their equivalent prices. Across all six pigeons, the mean ratio of generalized to specific tokens produced during the water component was 3.65, with individual

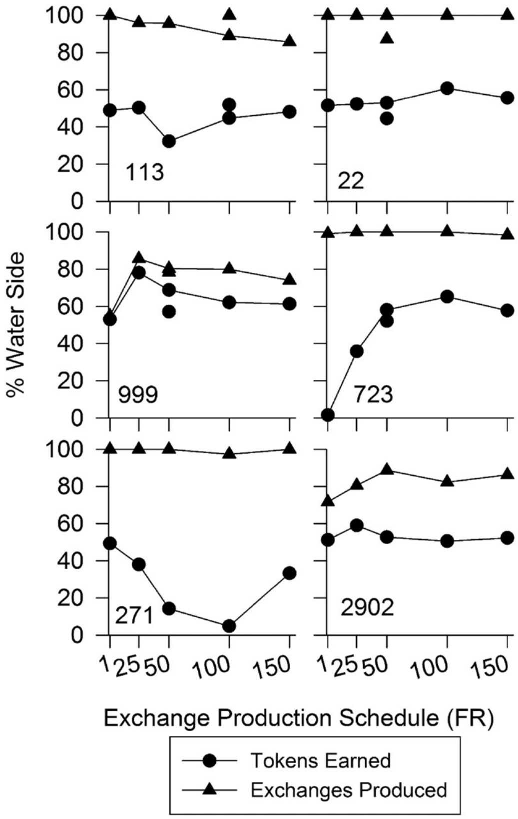

Fig. 4. Percent of tokens earned and percent exchanges produced on the water side of the chamber during the last nine sessions of each condition of Experiment 1B. To enhance the economy and clarity of display, conditions FR 200 and FR 250 for pigeon 113 are not shown. Across the last nine sessions of these two conditions, percent of tokens earned were 53.2% and 44.3%, respectively, and percents of exchanges produced on the water side of the chamber were 87.0% and 87.1%, respectively.

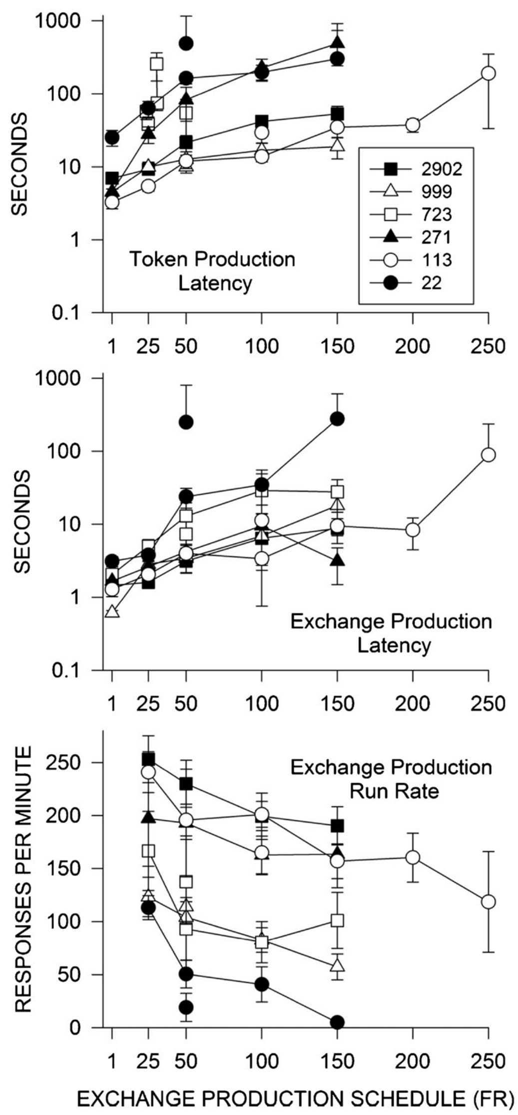

Fig. 5. Mean latency from the beginning of a cycle to the first token-production response (top panel), mean latency from the last token-production response to the first exchange-production response (middle panel), and mean response rate (excluding first-response latency) on the exchange production key, all as a function of exchange-production FR requirement in Experiment 1B. Disconnected open points show means from replication conditions. Error bars show standard deviations.

subject ratios ranging from 0.35 (Pigeon 271) to 10.04 (Pigeon 22). The fact that generalized tokens were preferred at all over equally-priced water tokens in the *Water* component suggests enhanced reinforcing efficacy of the generalized tokens, though the mixed preference patterns urge caution in the interpretation.

Figure 5 shows more local patterns of responding maintained by the token reinforcement schedules. The top panel shows mean latencies from the start of a cycle to the first token-production key peck, and the middle panel shows mean latencies from the last token-production key peck to the first exchange-production key peck (circles), from the last nine sessions of each condition. (In the rare cases in which a token-production key peck followed an exchange-production key peck, exchange-production latency was calculated using the time between the first exchange production key peck and the preceding token production key peck.) In general, token-production and exchange-production latencies increased as the exchange-production FR schedule increased. Token-production latencies were generally longer than exchange-production latencies. Both of these effects are consistent with prior research on token-accumulation procedures (Yankelevitz et al., 2008). That latencies were longer in the initial (token-production) segment than in the later (exchange-production) segment is consistent with the literature on extended-chained schedules (Bullock & Hackenberg, 2006; Kelleher, 1958; Kelleher & Gollub, 1962).

The lower panel of Figure 5 shows running response rates (excluding initial latencies) on the exchange-production key as a function of exchange-production FR schedule. In general, response rates decreased as exchange-production ratio increased, consistent with prior results on token-reinforcement procedures (Bullock & Hackenberg, 2006; Foster, Hackenberg, & Vaidya, 2001), including token-accumulation procedures (Yankelevitz et al., 2008), as well as with simple FR schedules (Mazur, 1983). In most cases, rates remained relatively high even at the highest exchange-production ratios. This is likely due to the proximity to the exchange period, also arranged on the center key.

Experiment 2

In Experiment 1, accumulation and response rates were shown to be sensitive to exchange-production price. Another method for assessing sensitivity to price is via manipulations in the costs of earning tokens—the token-production price. In economic terms, token-production manipulations permit an analysis of reinforcer elasticity: change in token production and consumption as a function of changes in price. In one phase of the present experiment, the price of generalized tokens was increased while the price of specific food and water tokens was held constant; in a second phase, the conditions were reversed: specific token price was increased while generalized token price was held constant. Both functions were obtained separately in water-restricted (Part 1) and food-restricted (Part 2) closed economies. We measured production/consumption of both token types (specific and generalized) with increases in their own price (own-price elasticity) and with increases in the price of the other (cross-price elasticity).

The latter is relevant to reinforcer interactions, such as *substitutability* and *complementarity*. Substitution effects would be indicated by increases in the production of one commodity (token type) with increases in the price of the other commodity (token type). Thus, increases in the production of the same-priced specific tokens with increases in the price of generalized tokens (Phase 1), or increases in the production of same-priced generalized tokens with increases in the price of specific tokens (Phase 2), would indicate a substitutable relationship. Parallel changes in the production of different token types would indicate a complementary relationship.

Method

Subjects and apparatus. The subjects and apparatus were identical to those used in Experiment 1, except that Pigeon 22 died prior to the food deprivation series (Part 2) of the experiment. Six pigeons thus participated in Part 1, and five pigeons in Part 2.

Procedure. The general procedure for individual sessions in this experiment was identical to the terminal procedure of Experiment 1b: token-production FR 1, exchange-production FR 25. The token-production schedules were manipulated across conditions, from FR 1 to at least FR 25, first for the generalized tokens (with specific token prices held constant at FR 1), then for the specific tokens (with generalized token prices held constant at FR 1). Both sequences were conducted under two different deprivation conditions: water (Part 1) and food (Part 2). The series of conditions comprising Part 1 was conducted immediately after the completion of training as described in Experiment 1b (i.e., prior to conducting the Experiment 1b terminal conditions, see Table 1), but is described out of chronological sequence for ease of exposition. During Part 1 conditions, pigeons were maintained at unrestricted weight and had free access to mixed grain while in the colony room. The food-deprivation series was conducted following the completion of Experiment 1b. The pigeons were placed on food restriction (as described in Experiment 1b Procedure, Part 2), and reduced to 83% of their free-feeding body weights. Table 4 shows the order of conditions and number of sessions per condition for all subjects in Experiment 2.

As in Experiment 1, all sessions lasted a maximum of 75 min. Sessions under water deprivation were terminated following the exchange period in which the 30th water delivery occurred, and sessions under food deprivation were terminated following the exchange period in which the 42nd food delivery occurred. These values permitted healthy levels of daily intake within sessions. There was no limit to the number of food deliveries that could occur during water deprivation sessions, and vice versa. Conditions were considered complete when a minimum of 10 sessions had been conducted and no trend was apparent in the total number of (green, red, and white) tokens earned and total number of (food and water) exchanges produced across the last nine sessions, when plotted as three-session means.

Results and Discussion

Figure 6 shows patterns of token exchange and overall food and water consumption across the final nine sessions of each condition in Experiment 2 (raw means and standard deviations are available in the Supporting Information that accompanies this article online). Water tokens were produced and exchanged predominately in Part 1 conditions, under water deprivation, and food tokens predominately in Part 2 conditions, under food deprivation. Generalized tokens were produced in both parts of the experiment and were exchanged mainly for water under water restriction (Part 1) and nearly exclusively for food under food restriction (Part 2). Such patterns of production and exchange show sensitivity of each token type to the arranged motivational conditions.

Within a given deprivation condition, preferences were systematically related to price. In baseline conditions in each of the four phases, when all three token types were available at a constant, low price (FR 1), no consistent preference developed across subjects for any token type (see token production at FR 1 in Figs. 7–10). As the price of the target token type was increased, however, preference for that token type decreased in favor of the alternate token type(s). These preference patterns were driven both by reduced token production of the changed-price token and increased token production of the same-priced token type.

The functions relating production of each token type to price are shown in Figures 7–8 from Part 1, conducted under water deprivation. In Phase 1, when the price of generalized tokens was altered while the price of specific water and food tokens was held constant, production of generalized tokens tended to decrease with increases in generalized token price (Fig. 7). In four of six cases, the decreases were monotonic, while for the other two pigeons (999 and 2902), the largest decreases were seen at the middle price (FR 10). Figure 8 shows comparable functions for Phase 2, in which the price of specific tokens was increased while the generalized token price was held constant. For all six pigeons, as the price of specific tokens was increased from 1 to 25, production of both food and water tokens decreased markedly.

In both phases, the price-driven changes in token production were accompanied by sometimes quite substantial increases in the production of the alternate token(s), the price of which did not change. The alternate commodities—specific tokens in Phase 1 and generalized tokens in Phase 2—thus served as partial substitutes for the changed-price token. These changes permitted roughly constant levels of water intake across the session (see Fig. 6).

Figures 9 and 10 show comparable conditions from Part 2, conducted under food deprivation. In Phase 1 (Fig. 9), when generalized token price increased across conditions while specific token price was held constant, demand was sensitive to price in both phases of the experiment, though to a far greater degree in Phase 2 (Fig. 10), in which the price of specific food and water tokens was increased while the generalized token price was held constant. Production of specific tokens eventually ceased altogether at FR 25, whereas much higher prices (up to FR 100, in some cases) were needed to produce comparable decreases in production of generalized tokens. Demand was thus far more elastic in Phase 2 (specific price change) than in Phase 1 (generalized price change).

As with the Part 1 conditions, price changes not only decreased production of the target token but also increased the production of alternate tokens, indicative of substitution effects. There was also evidence of complementarity, that is, parallel changes in demand. These were seen primarily by changes in the production of the nonrestricted commodity. In both parts of the experiment, pigeons occasionally produced and exchanged tokens for nonrestricted commodities, despite free access to that commodity outside the session. This perhaps reflects the strong complementary relationship

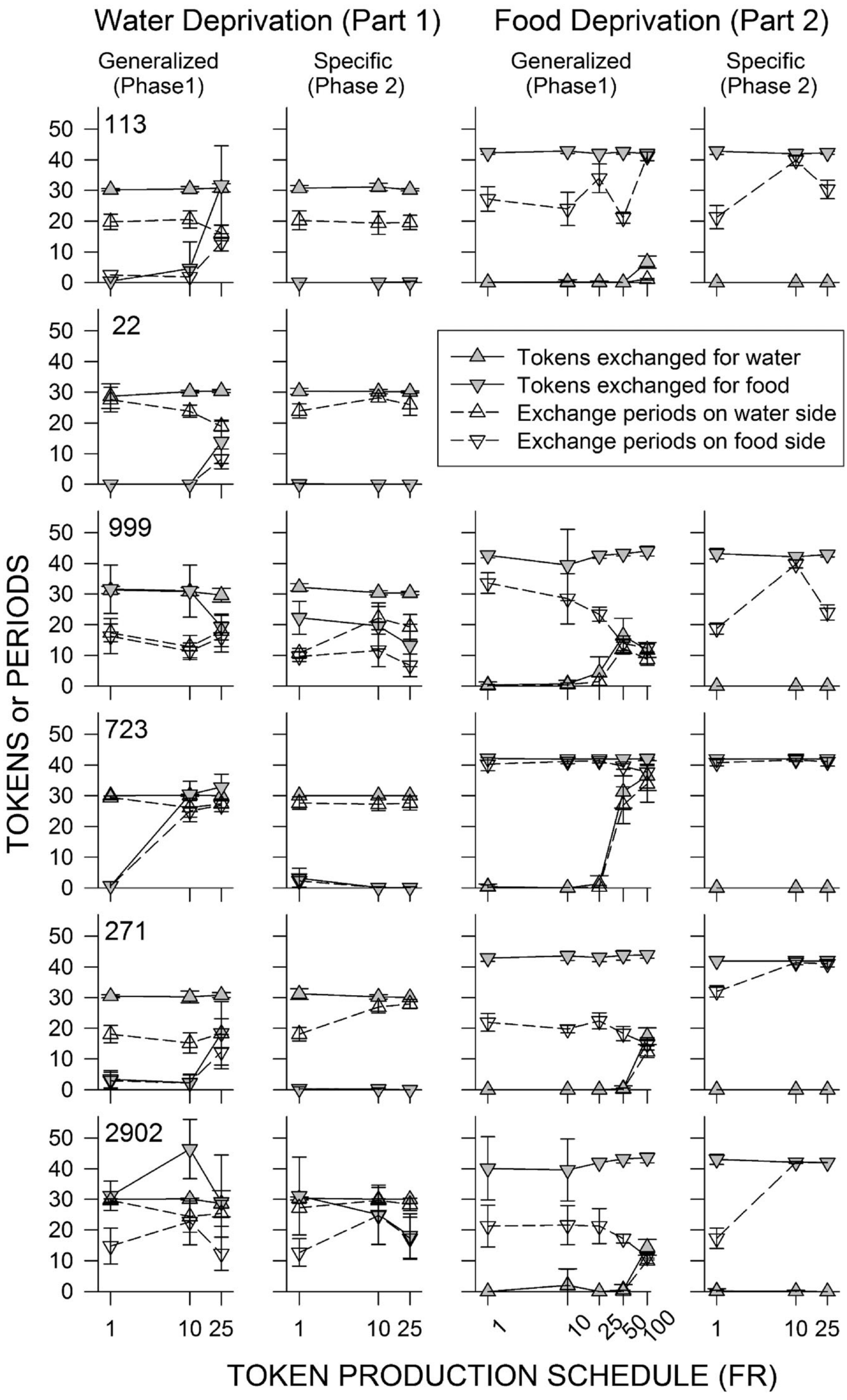

Fig. 6. Grey triangles and grey inverted triangles show mean tokens exchanged for water and food, respectively, in the last nine sessions of each condition of Experiment 2. These data are equivalent to the number of water and food reinforcers delivered. Open triangles and open inverted triangles show the mean exchange periods produced on each side of the experimental chamber. Token accumulation for conditions in Experiment 2 can be derived by dividing tokens exchanged for a particular commodity in a condition by the number of exchange periods produced on the relevant side of the chamber in that condition.

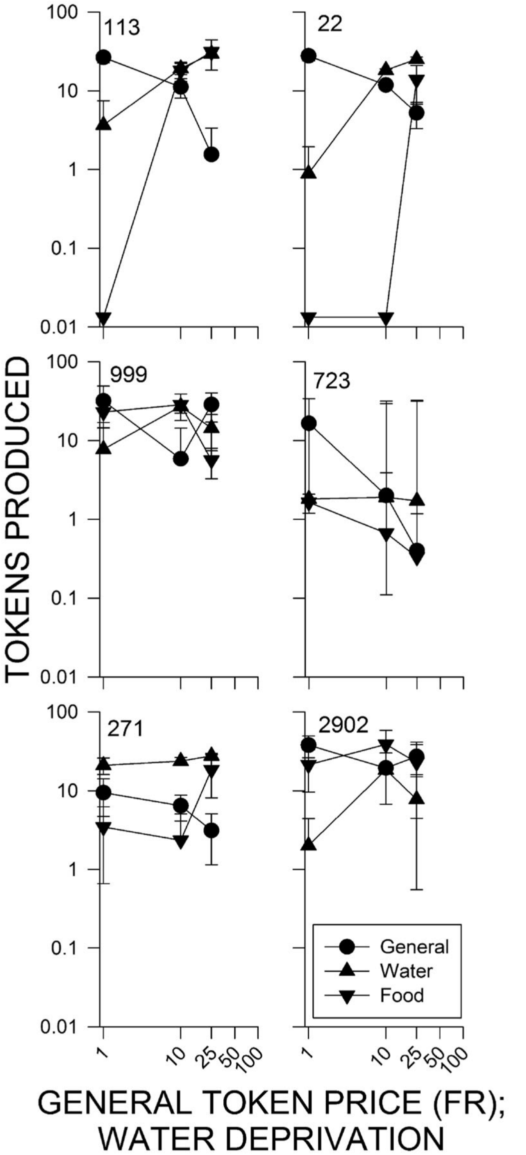

Fig. 7. Mean tokens per session earned on each token-production key as a function of generalized token-production FR price under water restriction conditions in Experiment 2. Production was normalized by expressing it as a percentage of production at the lowest price (FR 1). Disconnected points show means from replication conditions. Error bars show standard deviations.

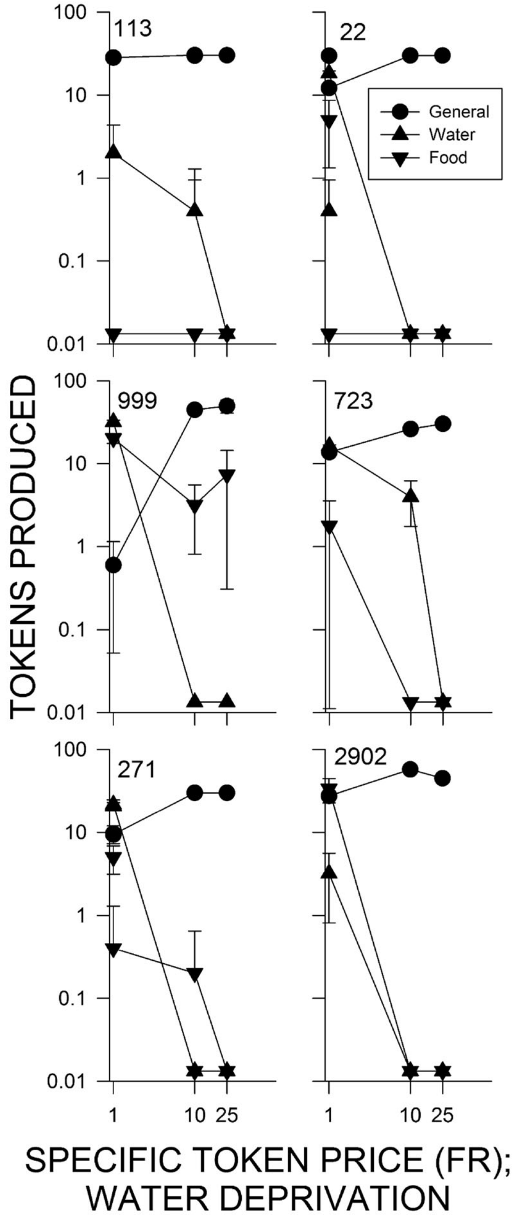

Fig. 8. Mean tokens per session earned on each token-production key as a function of specific token-production FR price under water restriction conditions in Experiment 2. See Figure 7 for additional details.

between food and water, as changes in the production of food tokens frequently accompanied parallel changes in production of water tokens (and vice versa). For example, in the first phase of Part 1, as generalized token production decreased with changes in price, production of both specific-water and specific-food tokens increased. It is worth noting that production of such nonrestricted commodities rarely occurred at prices exceeding FR 1, and was

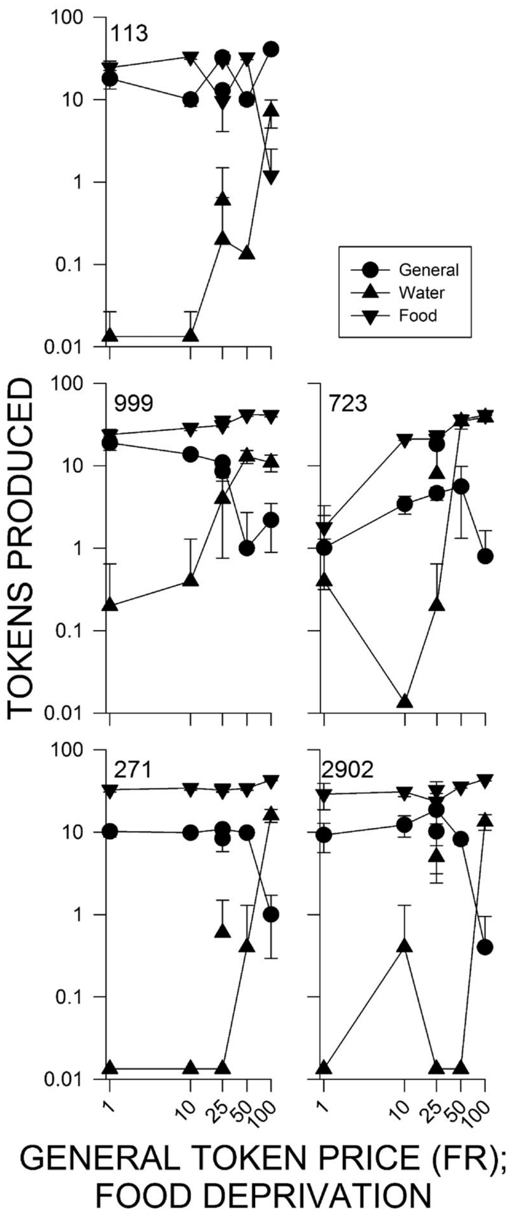

Fig. 9. Mean tokens per session earned on each token-production key as a function of generalized token-production FR price under food restriction conditions in Experiment 2. See Figure 7 for additional details.

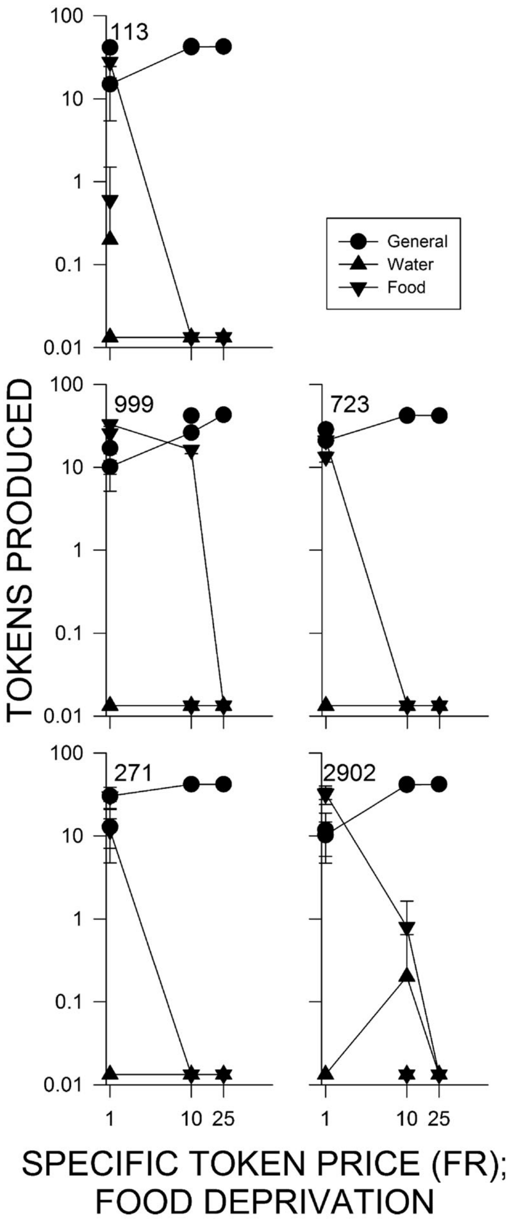

Fig. 10. Mean tokens per session earned on each token-production key as a function of specific token-production FR price under food restriction conditions in Experiment 2. See Figure 7 for additional details.

therefore quite sensitive to price (i.e., demand for nonessential goods was elastic).

More formal analyses of elasticity are presented in Table 5, which shows own-price and cross-price elasticity values for specific and generalized token types in both parts of the experiment (Part 1 in the left panels, and Part 2 in the right panels) for each subject in each phase. The generalized tokens (in boldface) are further subdivided by reinforcer type, depending on whether they were produced and exchanged on the food or water panel.

Table 5
Own- and cross-price elasticity values in Experiment 2.

		Part 1 (Water Deprivation)						Part 2 (Food Deprivation)					
Bird	Phase	Own	Own Water	Own Food	Cross	Cross Water	Cross Food	Own	Own Water	Own Food	Cross	Cross Water	Cross Food
113	1	–0.038	**–0.040**	–0.035	0.624	0.282	12.493	0.012	0.003	**0.056**	–0.006	0.657	–0.009
	2	–0.040	–0.040	–0.040	0.027	**0.077**	0.010	–0.040	–0.040	-0.040	0.093	0.012	**0.019**
22	1	–0.032	**–0.040**	–0.025	1.720	1.095	5.516	-	-	-	-	-	-
	2	–0.040	–0.040	–0.040	0.051	**0.846**	0.001	-	-	-	-	-	-
723	1	–0.038	**–0.038**	–0.038	0.148	0.054	2.850	–0.010	-0.009	**–0.010**	0.221	1.630	0.120
	2	–0.040	–0.040	–0.040	0.040	**0.536**	0.001	–0.040	-0.040	–0.040	0.041	0.000	**8.449**
999	1	–0.004	**–0.015**	0.020	–0.014	0.034	-0.030	–0.009	-0.009	**–0.010**	0.013	0.255	0.008
	2	–0.040	–0.040	–0.040	1.528	**0.862**	7.520	–0.040	-0.040	–0.040	0.127	0.010	**10.840**
2902	1	–0.011	**–0.013**	–0.009	0.013	0.116	0.003	–0.010	-0.010	**–0.010**	0.010	1.434	0.005
	2	–0.040	–0.040	–0.040	0.028	**0.009**	0.068	–0.040	-0.040	–0.040	0.123	0.059	**0.430**
271	1	–0.027	**–0.029**	–0.026	0.035	0.013	0.174	–0.009	-0.009	**–0.010**	0.009	1.734	0.003
	2	–0.040	–0.040	–0.040	0.097	**0.569**	0.027	–0.040	-0.040	–0.040	0.015	0.012	**0.019**

Note. Phase 1 and Phase 2 correspond to conditions in which generalized and specific token-production FR schedules, respectively, were manipulated. Numbers in boldface indicate values for Generalized tokens.

Own-price elasticity is computed here as percent change (from the lowest to the highest price) in production of a token divided by percent change in the price of that token, and cross-price elasticity as percent change in production of a token divided by percent change in the price of a second token type. Thus, own-price values would be negative if production is sensitive to price (e.g., production of token type A decreases with increasing price of A). Positive cross-price values would indicate a substitutable relation (production of A increases with increasing prices of B), whereas negative values would indicate a complementary relation (production of A decreases with increasing prices of B).

Across both parts of the experiment, mean own-price elasticity values were nearly always negative (21 of 22 conditions, across phases), characteristic of a typical demand function, and somewhat shallower (less negative) for generalized than for the specific tokens. Mean own-price elasticity values for generalized and specific tokens on the water side under water-deprivation in Part 1 were -0.029 and -0.040, respectively, and +0.003 and -0.040, respectively, on the food side under food deprivation in Part 2. In all of the 11 comparisons across both parts of the experiment, own-price elasticity values revealed that demand for generalized tokens was more inelastic than demand for specific tokens. Differences in own-price elasticity were especially evident under food deprivation (Part 2). When the price of generalized tokens was manipulated under food deprivation, high prices were required to produce decreases in token production. Even when generalized token prices were as high as FR 100, elasticity values were smaller than at FR 25 prices for specific tokens. When compared against similar price changes (FR 1 to FR 25), the elasticity differences are even more pronounced (not shown in Table 5).

Cross-price elasticity values for the deprived commodity (i.e., *Cross Water* in Part 1 and *Cross Food* in Part 2) were nearly always positive (21 of 22 conditions), characteristic of a substitution effect (e.g., as the price of generalized tokens increased in the food-deprivation conditions, pigeons increased their production of food-specific tokens). This effect was more pronounced in Phase 2 (specific-token price increases) than in Phase 1 (generalized-token price increases) conditions in 8 of 11 comparisons, indicating a stronger substitution effect for generalized than for specific tokens. These differences were especially evident in Part 2, under food deprivation, where cross-price elasticity values were uniformly higher for generalized than for specific tokens (all five comparisons). The mean cross-price elasticity values for generalized and specific tokens were +0.483 and +0.266, respectively, on the water side under water deprivation in Part 1, and

+3.951 and +0.025, respectively, on the food side under food deprivation in Part 2.

General Discussion

The present study is the first to demonstrate sustained generalized functions of a conditioned reinforcer in a laboratory procedure with nonhuman subjects. The strongest evidence for this interpretation comes from Experiment 2, in which the production of different token types was shown to vary with the relative costs of producing them. Production of a token varied inversely with its own price (own-price elasticity), characteristic of the typical demand function. Generalized and specific tokens were differentially sensitive to price changes; demand for specific tokens proved to be more elastic (i.e., more sensitive to price increases) than demand for generalized tokens.

Additional supporting evidence for this was observed in Experiment 1b, in which pigeons in a water-restricted economy tended to prefer generalized to specific tokens. In *Food* components of the multiple schedule, such preference enabled higher levels of water consumption, so may have functioned as link in a behavioral chain resulting in water. In *Water* components, however, the price (FR 1) and commodity (water) were equivalent for specific and generalized tokens. That over three times as many generalized as water-specific tokens were produced in these components suggests a reinforcing function of the generalized tokens, but variability across pigeons limits the strength of the finding.

The positive cross-price elasticity values in Experiment 2 are broadly consistent with a substitution effect. This type of functional substitution is often viewed as an important dimension of a generalized reinforcer, contributing to its overall reinforcing value. In Part 2, under food restriction, the cross-price elasticity values were indeed consistently higher for generalized than for specific tokens (Table 5), consistent with a substitution effect. Such differences in own-price and cross-price elasticity may suggest that generalized tokens are more effective reinforcers than specific tokens. While this would be consistent with some findings in Experiment 1b, and with standard views of conditioned reinforcement, a few caveats are in order. To begin with, there were some conditions in which the opposite effects were obtained: higher cross-price values for specific than generalized tokens in Part 1, suggesting that the substitutability was bidirectional. While this is at odds with the expected differences between generalized and specific reinforcers, it is not altogether surprising, given that these food and water tokens were available at a low price (FR 1) and in the same context as price increases for the generalized tokens. Substituting specific for generalized tokens therefore enabled maximum levels of water intake at low cost, and likely contributed to the mixed patterns of substitution across Part 1 conditions.

This availability of low-priced substitute reinforcers also likely changed the shape of the own-price functions. Given what is known about the influence of background sources of reinforcement (Herrnstein, 1970), demand should be more elastic as the reinforcement context becomes richer (defined in part by the presence of substitutable reinforcers). It will be important in future research to explore further the relationship between elasticity and background reinforcement context, including a wider range of prices permitting proper fits to current models (e.g., Hursh & Roma, 2013; Hursh & Silberberg, 2008). Also, because sessions terminated after a fixed number of reinforcers rather than a fixed number of responses, price changes produced concomitant income changes (i.e., number of responses per reinforcer). Future research should therefore use income-compensated price shift conditions to separate demand from income changes (e.g., Madden, Smethells, Ewan, & Hursh, 2007; Rachlin, Green, Kagel, & Battalio, 1976).

Future research might also profitably be directed to exploring a wider range of motivational conditions. Generalized reinforcers are said to derive their efficacy from relationships to multiple backup reinforcers, any one (or more) of which may be in demand at a given time. In this sense, generalized reinforcers are less tied than are specific reinforcers to particular deprivation conditions. In the present study, the generalized tokens were established as effective reinforcers by pairing them with food and water, but only one commodity (food *or* water) was in effect for a block of conditions, with the nonrestricted commodity freely available outside the experimental sessions. Thus, the value of the generalized tokens was restricted to the particular motivational conditions in place. In this sense, the generalized tokens in the present study fall perhaps closer to deprivation-specific reinforcers than to deprivation-general reinforcers. Future research should explore further this continuum of generalizability, expanding the range of motivational conditions and reinforcement contexts.

Token reinforcement systems are well suited to these types of follow-up experiments. As studied here and currently conceptualized (Hackenberg, 2009), token reinforcement procedures involve a series of interconnected contingencies with which to manipulate price and measure demand and preference. In addition to the aforementioned token-production price (*wages*, in economic terms—the costs of earning a unit of currency), a token reinforcement schedule also includes an exchange-production component (*procurement costs,* in economic terms—the costs involved in completing a purchase once tokens are earned). Such procurement costs arose in some conditions in Experiment 1b, in which generalized tokens earned on one side of the chamber were exchanged on the opposite side. In many conditions in the present study, the costs of walking to the opposite panel were offset by the differences in price for specific and generalized tokens.

Other conditions varied procurement costs directly via changes in the exchange-production FR (number of responses to produce an exchange opportunity). Consistent with prior research in which exchange-production costs have been shown to be strong determinants of response rate and preference (Bullock & Hackenberg, 2006; Foster & Hackenberg, 2004; Foster et al., 2001), exchange-schedule effects were seen in the present study most clearly in their relationship to response rate (Fig. 5) and token accumulation (Figs. 1–2). As the exchange-production price increased, response rates decreased (consistent with a demand analysis) and accumulation increased. This too is consistent with prior research (Yankelevitz et al., 2008), but the present study showed comparable functions with both food and water-specific tokens (Fig. 1) and a combination of token types (Fig. 2). Expanding the analysis of exchange-schedule effects to include a wider range of prices and economic conditions will provide important information on the viability of the token-accumulation procedure as a laboratory analogue of savings.

While extending the use of token systems to new domains, the present study also connects to prior work on extended sequence schedules, including but not limited to token reinforcement schedules. As a type of extended chained schedule, token reinforcement schedules produce temporally organized patterns of behavior, with response rates increasing across token-production segments leading to the terminal reinforcer (Bullock & Hackenberg, 2006; Foster et al., 2001; Waddell, Leander, Webbe, & Malagodi, 1972; Webbe & Malagodi, 1978). The differential latencies shown in Figure 5 are consistent with this general finding: Latencies at the outset of token-production components were consistently longer than those at the outset of exchange-production components. Such differential latencies, ordered with respect to proximity to the terminal reinforcer, may also reflect discriminative functions of the tokens. The token-production components always began with tokens absent whereas the exchange-production components began with at least one token present. Further evidence of the discriminative role of tokens came from the No-Token conditions in Experiment 1, which showed consistently lower levels of accumulation in the absence of tokens.

In conclusion, the present results build on prior research on token-reinforcement effects, but extend them to the realm of generalized conditioned reinforcement—a fundamental but neglected topic in the analysis of behavior. The work has clear relevance to behavioral economics and its emphasis on generalized monetary currencies. But the methods also have important implications for an analysis of conditioned reinforcement more generally. Nearly all that is known to date about conditioned reinforcement from laboratory experiments with nonhumans is based on specific-type conditioned reinforcers. A method for generating and sustaining the generalized conditioned reinforcing functions would not only expand our understanding of conditioned reinforcement, it would also help bridge the methodological gulf separating research with humans from that with other animals, sharpening cross-species analysis of behavior in various domains.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

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