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SUBSTITUTION EFFECTS IN A GENERALIZED TOKEN ECONOMY WITH PIGEONS

LEONARDO F. ANDRADE[1] AND TIMOTHY D. HACKENBERG[2]

[1]WESTFIELD STATE UNIVERSITY
[2]REED COLLEGE

Pigeons made repeated choices between earning and exchanging reinforcer-specific tokens (green tokens exchangeable for food, red tokens exchangeable for water) and reinforcer-general tokens (white tokens exchangeable for food or water) in a closed token economy. Food and green food tokens could be earned on one panel; water and red water tokens could be earned on a second panel; white generalized tokens could be earned on either panel. Responses on one key produced tokens according to a fixed-ratio schedule, whereas responses on a second key produced exchange periods, during which all previously earned tokens could be exchanged for the appropriate commodity. Most conditions were conducted in a closed economy, and pigeons distributed their token allocation in ways that permitted food and water consumption. When the price of all tokens was equal and low, most pigeons preferred the generalized tokens. When token-production prices were manipulated, pigeons reduced production of the tokens that increased in price while increasing production of the generalized tokens that remained at a fixed price. The latter is consistent with a substitution effect: Generalized tokens increased and were exchanged for the more expensive reinforcer. When food and water were made freely available outside the session, token production and exchange was sharply reduced but was not eliminated, even in conditions when it no longer produced tokens. The results join with other recent data in showing sustained generalized functions of token reinforcers, and demonstrate the utility of token-economic methods for assessing demand for and substitution among multiple commodities in a laboratory context.

Key words: token reinforcement, generalized conditioned reinforcement, concurrent schedules, behavioral economics, key peck, pigeons

Generalized conditioned reinforcers are reinforcers whose functions are established and maintained through their relationship to two or more existing reinforcers (Skinner, 1953). Money is the textbook example of a generalized reinforcer, the functions of which hold across a broad range of circumstances. It is generally assumed that generalized reinforcers are more effective as reinforcers than their specific counterparts (related to a single terminal reinforcer and motivational condition), due largely to the multiple reinforcers that give rise to them. Generalized reinforcers should therefore retain their reinforcing efficacy across a wider range of motivational conditions, only one of which need be present at the time of the response.

As plausible as this assertion is from a theoretical point of view, the analysis of generalized reinforcement is in its infancy. Few data exist on the topic, and little is currently known about even the most basic functions of generalized reinforcement. The present study aimed to explore some basic functions of generalized reinforcement, building on recent research with pigeons in a token economy (DeFulio, Yankelevitz, Bullock, & Hackenberg, 2014; Tan & Hackenberg, 2015). In the DeFulio et al. study, a dual intelligence panel was used, whereby specific-food tokens could be produced on one side panel and exchanged for food, specific-water tokens could be produced on the other side panel and exchanged for water, and generalized tokens could be produced on either panel and exchanged for either food *or* water. A token-accumulation procedure was used, in which responses on one key produced tokens, and responses on a second key produced exchange periods during which tokens could be exchanged for the relevant terminal reinforcer (or reinforcers): red tokens exchangeable for water, green

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Address Correspondence to Leonardo F. Andrade, Psychology Department, Westfield State University, 577 Western Avenue, Westfield, MA 01086, USA. (email: landrade@westfield.ma.edu)

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tokens for food, and white tokens for either water or food.

In some conditions, food was freely available outside the sessions but water was restricted. *Food* and *Water* panels alternated regularly throughout the session, in a multiple schedule format, such that the pigeons sometimes chose between specific food and generalized tokens and sometimes between specific water and generalized tokens. In parts of the session in which only the *Food* panel was operative, pigeons increased their production of generalized tokens, where they were subsequently exchanged for water on the opposite panel (consistent with the water-restricted economy). In other words, the generalized tokens served as partial substitutes for water tokens—produced and exchanged for access to the restricted reinforcer.

These results are broadly consistent with the more formal definition of substitution—as changes in production of one commodity with changes in the value of a second commodity (Green & Freed, 1993; Hursh, 1984). A more typical method for examining substitution effects is to measure production of two commodities, one for which the price changes while the other is held constant. In a second experiment in the DeFulio et al. (2014) study, token-production prices (arranged as fixed ratio [FR] schedules) were systematically altered across conditions, separately for generalized and specific tokens, and under both food and water restriction. Production of generalized tokens decreased with increases in the price of generalized tokens (own-price elasticity) and increased with increases in the price of the specific token (cross-price elasticity). The latter is consistent with a substitution effect—the generalized tokens functionally substituted for the higher-priced specific tokens. Production of food-specific and water-specific tokens, on the other hand, changed together, indicating a complementary relationship.

The own-price findings were replicated by Tan and Hackenberg (2015) over a much wider range of prices and motivational conditions, permitting greater quantitative precision. On the whole, the data were well described by Hursh and Silberberg's (2008) essential value model, which accounted for over 90% of the variance. In some conditions designed to assess substitution effects, the price of the generalized and specific tokens changed together, in pairwise choices between (a) food tokens and water tokens; (b) food tokens and generalized tokens; and (c) water tokens and generalized tokens. The price of each token type systematically increased together across conditions in a closed economy, in which all food and water intake occurred in 3-hr daily sessions. Of particular interest was whether, when pitted against food or water tokens, more generalized tokens would be produced and exchanged for the reinforcer (food or water) that was otherwise unavailable within the session. This is indeed what happened: The generalized tokens substituted for food when food tokens were unavailable (in choices between generalized and water tokens) and for water when water tokens were unavailable (in choices between generalized and food tokens). This functional substitution enabled the pigeons to maintain levels of food and water intake roughly comparable to conditions with choices between specific food and water tokens.

The present study also explored substitutability of generalized reinforcers in a token economy with pigeons. A dual-intelligence panel apparatus was used, as in DeFulio et al. (2014), in which food tokens could be earned on one panel, water tokens on an opposite panel, and generalized tokens on either panel. However, unlike prior research, in which only two options were concurrently available (generalized and specific), the present study expanded the number of concurrent options. The food and water panels were available simultaneously, affording the pigeons four concurrent options for token production: food tokens on the food panel, water tokens on the water panel, generalized tokens on the food panel, and generalized tokens on the water panel.

Expanding the number of options permits a more detailed characterization of generalized token reinforcement as a function of price and motivational/economic conditions. In Phase 1, the price of both specific and generalized tokens on one panel (either food or water) increased, while the price of both token types on the alternate panel was held constant. Thus, for example, in one set of conditions, the price of both tokens on the food panel increased from FR 5 to FR 50, while the price of tokens on the water panel remained the same (FR 5). In another set of conditions, the conditions were reversed: The price of water tokens increased, while the price of food tokens remained the same. This enabled an assessment of sensitivity of each commodity type to increases in its own price (own-price elasticity) and to increases in the price of the alternate commodity (cross-price elasticity). Of particular interest was whether the generalized tokens would substitute for the alternate reinforcer; more specifically, would production of the constant-priced (FR 5) generalized tokens increase with price increases on the alternate panel—tokens that could then subsequently be exchanged for food as well as water? This type of functional substitution, a critical characteristic of a generalized reinforcer, was assessed in both directions—that is, in the face of separate price changes with respect to food and water.

A second major aim was to examine the effects of broad changes in the economy on the production and exchange of the different token types. In most previous research on generalized reinforcement, the economy was only partially closed—that is, restricted postsession access for one reinforcer while unlimited access for the other. For example, in conditions in a food-restricted economy in the DeFulio et al. (2014) study, daily access to food occurred within the session, whereas water was available both inside and outside the session. The economy was thus closed with respect to food but open with respect to water. And the same holds true for water-restricted economies—they are typically closed with respect to water but open with respect to food. To the extent that an open economy of either type includes substitutable reinforcers (e.g., similar reinforcers available inside and outside the session), the economic contingencies within the session are weakened.

One exception to this general rule was Experiment 3 in the Tan and Hackenberg (2015) study, conducted in a fully closed economy, in which pigeons consumed all of their food and water in daily 3-hr sessions. The present study also used a closed economy as the standard, in which all food and water intake occurred within the session. This was designed to eliminate interactions with postsession reinforcers, enhancing the contingencies within the token economy. This type of closed economy was in place during all of the conditions in Phase 1 and the baseline conditions in Phase 2. These *Closed economy* conditions were compared in Phase 2 to *Open economy* conditions, in which food and water were freely available outside sessions. The price of all tokens was held constant (FR 5) while the economic context was systematically varied across blocks of conditions. It was expected that the functions of both specific and generalized tokens would be enhanced in the closed economy, owing to the more direct relationship between token-based responding and daily intake levels.

Of interest was whether, or to what extent, responding would be maintained at all in the open economy, with free access to food and water outside the session. Previous research has shown that a generalized reinforcer (a flashing light previously correlated food and water) maintained discriminative performance even in the absence of food and water deprivation (Lubinksi & Thompson, 1987). In that study, however, the sessions were short (five trials) and exposure was brief (introduced as one-session probes). The present study sought to explore such deprivation-free effects of generalized reinforcers over much longer time periods and in relation to other response-weakening procedures: extinction and token omission. Together with the price-change conditions from Phase 1, these conditions were arranged to shed further light on the mechanisms governing generalized reinforcement in token economies.

Method

Subjects

Four White Carneau pigeons (*Columba livia*) (numbered 999, 271, 723, and 113) served as experimental subjects. The pigeons were housed in separate cages where they had continuous access to grit. Body weights were unrestricted, yet remained high (>90% free feeding weights) across both phases of the experiment, whether food and water were restricted outside of sessions (*Closed economy*) or not (*Open economy*). In the rare sessions in which pigeons obtained less than 10 mL of water, 20 mL supplementary water was provided following the session. The colony room was illuminated on a 16:8 hours light/dark cycles, and was temperature- and humiditycontrolled. The study was approved by the university's Institutional Animal Care and Use Committee.

Apparatus

A rectangular operant conditioning chamber measuring 50 cm long by 35 cm wide by 39 cm high served as experimental space. The working space included two modified stimulus panels, located at opposite sides of the chamber. Each stimulus panel contained three horizontally aligned response keys located 15 cm from the top. The response keys were located 6 cm apart from each other and required a minimum force of 0.12 N to register a response. One of the intelligence panels contained a food hopper used to deliver mixed grains accessed through an aperture measuring 5.8 cm wide by 5.0 cm high. The hopper contained a white light activated every time food was delivered. The other intelligence panel contained an infusion pump (Med Associates®) used to deliver water from a large syringe to a plastic cup, measuring 2.5 cm in diameter and located at 11 cm from the grid. A white light illuminated the cup during water deliveries.

A row of 12 evenly spaced lights was inserted 7.5 cm from the top of each stimulus panels and served as tokens. Tokens measured 2 cm diameter and could be illuminated green, red, or white. Specific food and water tokens were located on the left side of each intelligence panel whereas the generalized tokens were located on the right side of each panel. The six left-most tokens were illuminated green on the food panel and red on the water panel; the six right-most tokens on both panels were illuminated white. The chamber contained two houselights, each located 4 cm from the ceiling on each intelligence panel. The experiment was controlled by a computer and MED-PC IV® interface and software.

Procedure

All pigeons had prior histories in similar operant conditioning experiments using tokens exchangeable for food and water, so no training was required. For a detailed description of prior training, see DeFulio et al. (2014). It is worth noting here that the pigeons had specific experience with each of the token types (food, water, and generalized) on both panels, including producing a generalized token on one side panel and exchanging it on the other.

The sessions lasted 90 min, during which pigeons obtained all their daily food and water intake. Concurrent four-alternative token-production schedules were used, in which pigeons were given repeated choices between producing green (food) tokens on the food panel, white (generalized) token on the food panel, red (water) tokens on the water panel, and white (generalized) tokens on the water panel. Green and red tokens could be exchanged for only food and water, respectively, whereas white tokens could be exchanged for either food or water. At the beginning of each choice cycle, the houselights and both side keys on each panel were illuminated: The left key of the food panel was illuminated green, and the right key white; the left key of the water panel was lit red and the right key white. Responses on the side keys produced tokens according to a fixed-ratio (FR) schedule of reinforcement. Thus, after a specific number of responses were emitted on a given side key, a token was produced. Tokens were presented from left to right if responses had been on the left token production key, or from right to left if responses had been on the right token production key.

All four token production keys and tokens (if any had been earned) on both panels remained on until a token of any type was earned. This also produced the exchange production schedule, signaled by a yellow center key. (If a generalized token was produced, the center yellow key was illuminated on both panels.). A single response on the center yellow light produced the exchange schedule on that specific panel, which was signaled by the darkening of the center key and the flashing of the side key(s) associated with the token(s) produced. Thus, if a food token had been produced, the green side key on the food panel would flash, a single peck on which would produce 3 s of food. If a water token had been produced, the red side key on the water panel would flash, a single peck on which would produce 0.6 cc of water. If a generalized token had been produced, the white side key on the water or food panel would flash, a single peck on which would produce 3 s of food or 0.6 cc of water, depending on which panel the token was being exchanged. A single peck on the green or white keys on the food panel would produce food whereas a peck on the red or white keys on the water panel would produce water. Tokens could thus be earned on both sides, but could only be exchanged on one side. In addition to producing either food or water (depending on the panel where the exchange occurred), token exchange also produced a brief auditory stimulus and darkened a token light. Immediately after all tokens had been exchanged, a new cycle was initiated, with all four token production schedules again in place.

Phase 1. In this phase, pigeons were exposed to a series of conditions in which the response requirements of the token production schedule varied systematically across conditions, in a within-subject A-B-A-C experimental design. In A (baseline) conditions, the token production schedules were the same (FR 5) for all four token types. In B conditions, the token production schedule on the *Water* panel was held constant at FR 5, while the token production schedule on the *Food* panel increased across conditions from FR 5 to FR 50 (and FR 100 for Pigeon 113). In C conditions, the token production schedule on the *Food* panel was held constant at FR 5, while the token production schedule on the *Water* panel increased across conditions from FR 5 to FR 50 (and FR 100 for Pigeon 113). Table 1 shows the sequence of conditions and the number of sessions conducted at each.

Phase 2. In this phase, pigeons were again given repeated choices between earning and exchanging specific and generalized tokens using concurrent schedules of reinforcement containing four choice alternatives. The experimental procedures were similar to those in Phase 1, but the response requirements of the token production schedule remained constant across all conditions (FR 5) during this experiment. Experimental conditions consisted of blocks of sessions conducted under two different economy types: *Closed* (food restricted outside the session, as in Phase 1), and *Open* (unrestricted access to food and water outside the session). These economy types alternated according to an A-B-A-B sequence on a within-subject basis, with A (baseline) corresponding to *Closed* economy and B to *Open* economy conditions. Under each economy type, an extinction condition was conducted, in which tokens continued to be produced under a FR 5 schedule, but they were no longer exchangeable for food or water. Each peck on the flashing exchange-key produced only the darkening of a token light, and a brief beep. (Because neither food nor water was available in *Extinction* conditions under the *Closed* economy, pigeons were given postsession food and water based on their average daily intake measured during the last 10 sessions of the preceding condition.) In addition to these four main conditions, a final condition (*No-token*) was conducted in the second B (*Open* economy), in which responses did not produce tokens but continued to produce exchange periods and the terminal reinforcers (food and water). The sequence of conditions and the number of sessions conducted at each is shown in Table 2.

In both phases of the experiment, conditions were changed when the relative frequencies of token production were stable according

Table 1

Token-production schedule on the Water and Food panels, and total number of sessions conducted in each experimental condition in Phase 1.

			Subject			
Condition	Food Panel	Water Panel	999	723	271	113
A	FR5	FR5	34	58	78	32
B1	FR50	FR5	37	20	28	30
B2	FR100	FR5	-	-	-	37
A	FR5	FR5	34	38	23	29
C1	FR5	FR50	23	30	18	20
C2	FR5	FR100	-	-	-	39

Table 2

Order of experimental conditions and total number of sessions conducted at each in Phase 2.

	Subject			
Condition (Economy type-Procedure)	999	723	271	113
A: Closed	36	20	33	51
B: Open	27	38	17	41
B1: Open - EXT	6	6	6	6
A: Closed	27	36	23	21
A1: Closed- EXT	11	6	7	8
A: Closed	18	30	39	17
B: Open	40	14	17	22
B2: Open – No token	71	28	39	15

the following criteria: (a) absence of five-session trends; and (b) neither the highest nor lowest token production rates occurred in the last five sessions.

Results

Phase 1

Mean tokens produced on each token production key is shown in Figure 1 for all subjects across the final five sessions of each condition in Phase 1, in which the token-production requirements were systematically altered across conditions. (Response rates were also analyzed in relation to the experimental conditions, but these largely paralleled the token-production rates, so are not considered further here.) Across all conditions, the pigeons distributed their token production responding in ways that permitted both food and water access. Over the final five sessions of A (baseline) conditions, when the price of all tokens was equal and low (FR 5), pigeons produced an average of 202 tokens per session (range: 124–172), 79% of which were produced and exchanged on the food panel. Three pigeons (999, 271, 113) earned predominantly generalized tokens in baseline (accounting for 70-100% of the total), whereas the other pigeon (723) earned mostly specific tokens (89% of the total).

In B conditions, when the price of food and generalized tokens on the food panel increased, all pigeons reduced production of tokens on the food panel and increased production of constant-price generalized tokens on the water panel. This effect occurred for three pigeons (999, 723, 271) at a price of FR 50, whereas for a fourth pigeon (113) a higher price (FR 100) was needed. The majority of these generalized tokens were then exchanged for food on the food panel. Similarly, in C conditions, when the price of water and generalized tokens on the water panel increased, most pigeons reduced production of the tokens on the water panel and increased production of the generalized tokens on the food panel; the tokens were mostly exchanged for water.

Sensitivity to price changes can be quantified in terms of demand elasticity. Table 3 shows demand elasticity values over the final five sessions of each condition, computed as: proportion change in token production / proportion change in price. (Only the highest prices per subject are shown; hence FR 100 for Pigeon 113, and FR 50 for the other three subjects.) In B conditions, when food prices increased, own-price elasticity (proportion change in food tokens / proportion change in food price) was strongly negative (mean = −1.07), typical of the downward sloping demand function. Conversely, overall cross-price elasticity values (proportion change in production of water tokens / proportion change in price of food) were strongly positive (mean = +1.00), with generalized tokens accounting for 87% of the total tokens earned on the water panel. Note also the consistently higher elasticity values for generalized versus specific tokens, indicating that most of the changes in the overall values were driven by changes in generalized token production. Similar effects were seen in C conditions, when water prices increased: Own-price elasticity values were strongly negative (mean = −0.95), and the cross-price values were positive (mean = +0.15), with generalized tokens accounting for 77% of the tokens earned on the food panel.

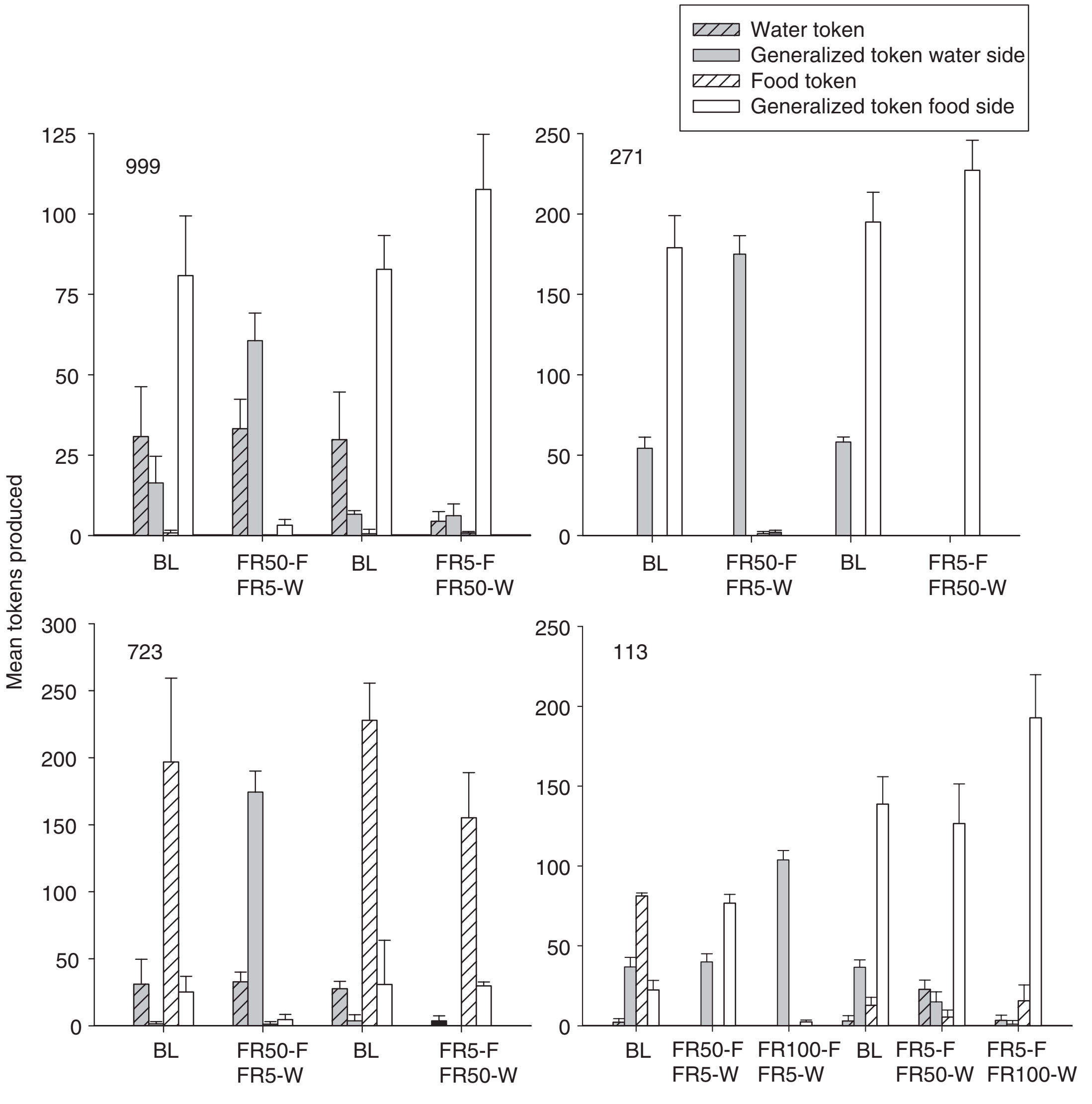

Fig. 1. Mean (and SD) tokens produced on each token production key for each subject over the last five sessions of each condition in Phase 1. BL, FR, F, and W refer to baseline, fixed-ratio, food, and water, respectively. Note that the y-axis scales vary by subject.

Figure 2 shows the token-exchange distributions—the mean number of food and water reinforcers for which tokens of each type were exchanged over the final five sessions of each condition. In baseline conditions, the pigeons distributed their exchanges among the different token types, with the majority of tokens exchanged for food. In these conditions, pigeons rarely exchanged generalized tokens on the opposite panel; that is, generalized tokens on the food panel were exchanged for food and generalized tokens on the water panel were exchanged for water. In B conditions, however, when the price of the tokens on the food panel increased, pigeons increased production of generalized tokens on the water panel and exchanged them for food on the food side. And in C conditions, when the price of the tokens on the water panel increased, pigeons increased production of generalized tokens on the food side and exchanged them for water on the water side.

Table 3

Own-price and cross-price elasticity values (proportion change in tokens produced / proportion change in price) for all subjects in price-change conditions in Phase 1: B (when food prices changed) and C (when water prices changed). Own-price and cross-price columns show elasticity values for combined (specific and generalized) tokens, whereas the other columns (Spec, Gen) show the same measure for each token type separately. See text for additional details.

Pigeon	Condition	Own price	Own-Spec	Own-Gen	Cross price	Cross-Spec	Cross-Gen
999	B: food	−1.07	−1.11	−1.07	+0.55	+0.09	+2.99
	C: water	−0.79	−0.95	−0.07	+0.33	+0.37	+0.33
723	B: food	−1.08	−1.10	−0.91	+0.94	+0.06	+137.30
	C: water	−0.98	−0.97	−1.11	−0.32	−0.35	−0.04
271	B: food	−1.10	0	−1.10	+0.77	0	+2.48
	C: water	−1.11	0	−1.11	+0.18	0	+0.18
113	B: food	−1.03	−1.05	−0.94	+1.75	−1.05	+1.92
	C: water	−0.94	0.14	−1.03	+0.39	+0.23	+0.55

Phase 2

Figure 3 shows the mean number of tokens of each type produced by each pigeon across the final five sessions of each condition in Phase 2, in which the economy type (closed or open) was systematically altered across conditions. Unlike some conditions in Phase 1, where tokens were produced on one panel and exchanged on the other, nearly all of the tokens in Phase 2 were produced and exchanged on the same panel. The token-production and token-exchange distributions were therefore quite similar, and so only the token-production distributions will be discussed. In the block of conditions conducted in A (*Closed economy*) conditions, with food and water only available within the session, the overall rates and patterns of token production and exchange were comparable to Phase 1 baselines. On average, the 236 tokens earned per session (range = 138–288), in the three baseline conditions in Phase 2 were comparable to the 202 earned in the two baseline conditions in Phase 1 (range = 124–272), as were the patterns of token allocation: Pigeons earned and exchanged 77% of the tokens for food and 23% for water (compared to 79% and 21% in Phase 1).

In the blocks of conditions conducted in B (*Open economy*) conditions, with food and water freely available outside of sessions, token production and exchange decreased substantially, less than 19% of the baseline (*Closed economy*) conditions (from 236 to 44 tokens, on average). When tokens were produced in the *Open economy*, the vast majority (93%) were earned and exchanged on the food panel. And while the overall rates of token production were reduced, the baseline token preferences were maintained, with Pigeon 723 preferring specific food tokens and the other three pigeons preferring the generalized food tokens.

In *Extinction* conditions, when tokens could be produced but not exchanged, token production decreased sharply to low levels in a few sessions for all subjects under both economy types. In the *No-token* conditions, when responding could produce food or water but without tokens present, token production decreased relative to the prior condition with the added tokens, but was not eliminated, occurring at 78% of the rates in the prior condition.

Discussion

The present results join with other recent findings in revealing further the behavioral functions of generalized reinforcers in a token economy with pigeons. In baseline conditions in both phases of the study, in which all four token types were available at a low price (FR 5), responding was robust: The pigeons, on average, produced and exchanged in excess of 200 tokens per 90-min session, approximately 80% on the food panel and 20% on the water panel. In the price-change conditions, in which the price of tokens on a given panel increased while that of tokens on the other panel remained the same, pigeons reduced the production of the tokens that increased in price (own-price demand elasticity) while increasing the production of the generalized tokens that remained at a fixed price (cross-price demand elasticity).

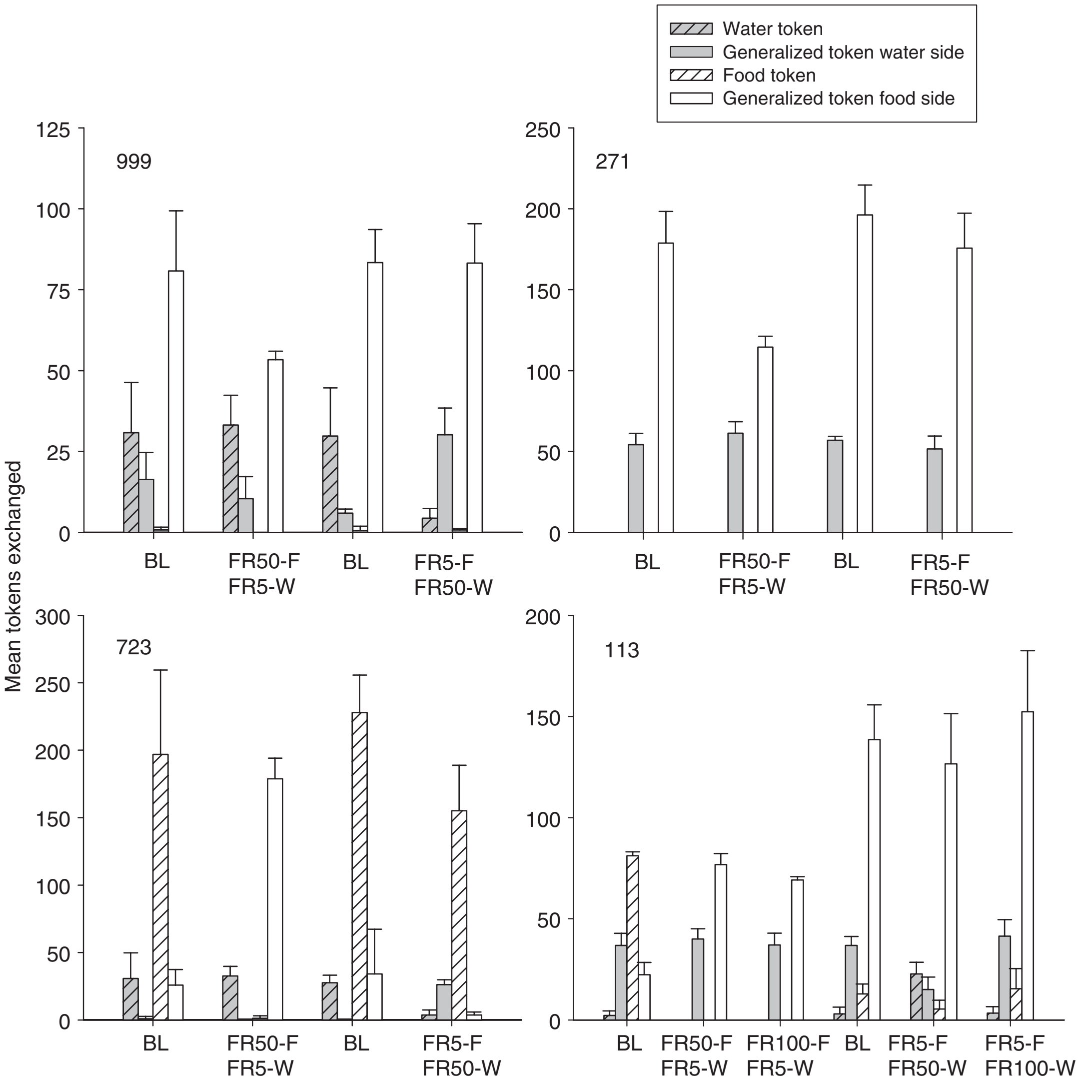

Fig. 2. Mean (and SD) tokens exchanged on each token exchange key for each subject from the last five sessions of each condition in Phase 1. BL, FR, F, and W refer to baseline, fixed-ratio, food, and water, respectively. Note that the y-axis scales vary by subject.

Similar own-price and cross-price demand elasticity was seen across both conditions (i.e., in the face of price changes for both food and water), but differed in quantitative detail. The own-price elasticity values were strongly negative in both B (food-price changed) and C (water-price changed) conditions in Phase 1 (Table 3), typical of own-price demand functions in which consumption declines with price. In the present case, reductions in token production were nearly proportional to price changes. Although the values were slightly more negative in B (food) than in C (water) conditions, both commodities fell in the elastic range of the own-price elasticity continuum, highly sensitive to price.

The cross-price elasticity values shown in Table 3 were positive in both price-change conditions, indicating substitutable commodities. The higher cross-price values in B (price changes for food) than in C (price changes for water) suggest stronger substitutability of generalized tokens for food than of generalized tokens for water. Indeed, the strong and

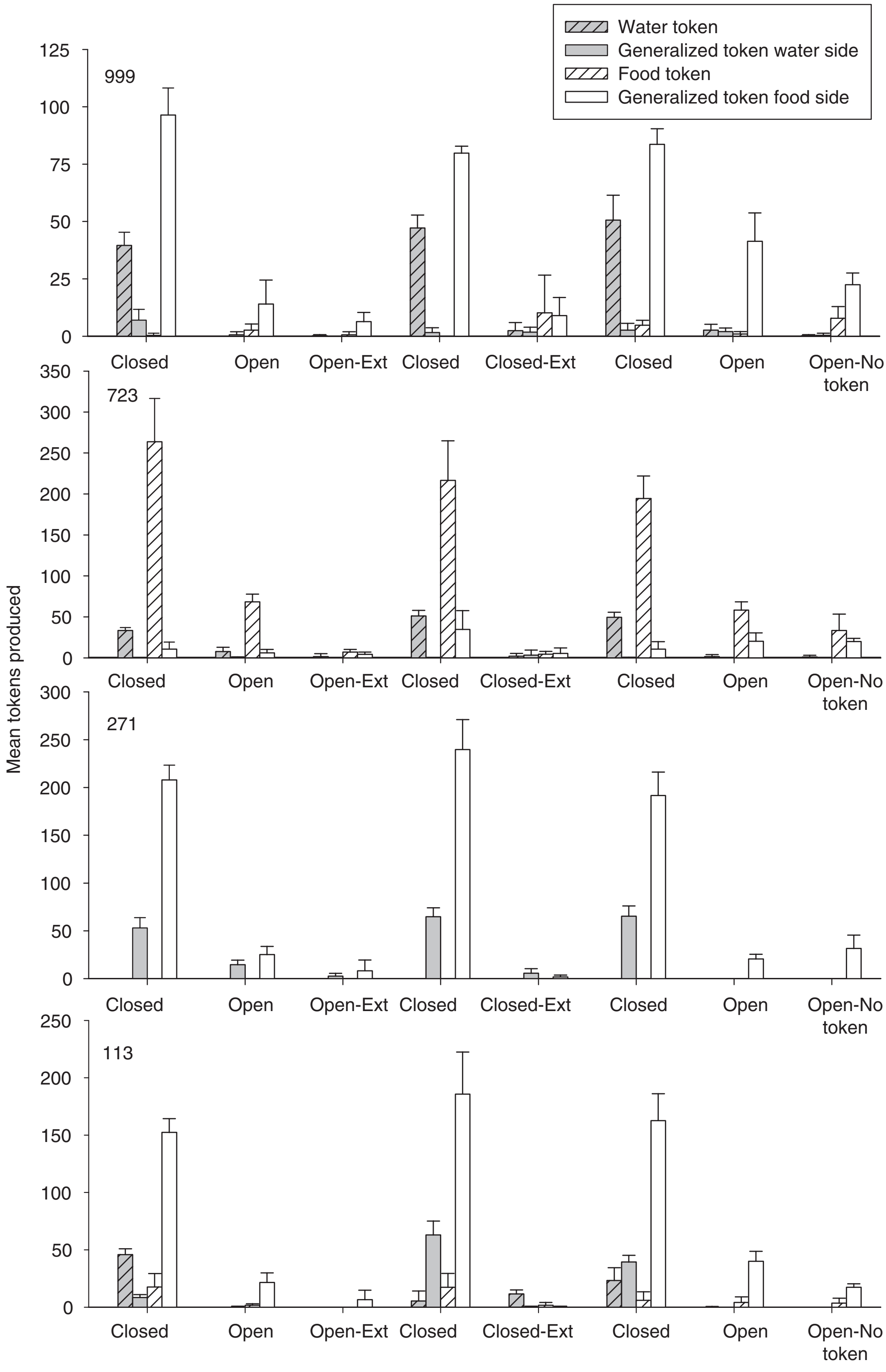

Fig. 3. Mean (and SD) tokens produced on each token production key for each subject over the last five sessions of each condition in Phase 2. Closed, Open, and Ext refer to closed economy, open economy, and extinction conditions, respectively. Note that the y-axis scales vary by subject.

nearly proportional *increases* in water tokens with price increases for food (the majority of which were generalized tokens), coupled with the strong and nearly proportional *decreases* in food tokens, suggest that the generalized tokens served as nearly perfect substitutes for food tokens in B conditions. The relatively smaller increases in generalized tokens in C conditions suggest that the tokens served as partial substitutes for water tokens. The generalized tokens therefore served as functional substitutes for both food and water tokens, though to varying degrees. One of the benefits of an analysis couched in terms of demand elasticity is this type of quantitative precision, from which it is possible to specify the nature and degree of interaction between multiple reinforcers.

The selective substitution that occurred under price-change conditions is consistent with prior results (DeFulio et al., 2014; Tan & Hackenberg, 2015), and underscores an important function of generalized reinforcers—that of standing in place of other reinforcers. Indeed, such selective substitution, in which generalized reinforcers are earned and exchanged for multiple reinforcers, may be a distinctive function of generalized reinforcers, and key to their reinforcing efficacy. It accounts well for the changes in token production in the price-change conditions in Phase 1, where generalized tokens came to functionally substitute for food tokens (when food prices increased in B conditions) and for water tokens (when water prices increased in C conditions). Selective substitution is also consistent with previous findings, where generalized token production increases in the face of price challenges to other reinforcers (DeFulio et al., 2104; Tan & Hackenberg, 2015).

Token production is only one component of a fully substitutable relationship; the other is what the tokens are exchanged for—*expenditures*, in economic terms. In the present results, these expenditures were consistent with the price changes: The generalized tokens were spent in ways that mitigated losses in intake that would otherwise accompany the sharp price increases. Despite ten-fold increases in price, mean number of tokens produced and exchanged per session dropped only 18% from baseline to the price-change conditions (Figs. 1 and 2). Substituting relatively cheaper generalized-water tokens for relatively more expensive food tokens in Condition B, and cheaper generalized-food tokens for more expensive water tokens in Condition C enabled the pigeons to maintain reasonably high levels of food and water intake (77% of baseline levels) in the face of the steep price increases. When reduction in intake did occur, it was mostly seen with respect to food; water exchanges were unchanged, strongly resistant to price changes.

Selective substitution of less expensive generalized reinforcers for more expensive alternate reinforcers therefore makes good adaptive sense, and should be selected as a behavioral pattern of token production and exchange in the present economy. While this may help account for results from conditions in which access to one or more reinforcers is restricted or made more costly, it does not explain preference for the generalized tokens in conditions in which generalized and specific tokens are both available at the same prices (e.g., as in the present baseline conditions). Three of the four pigeons consistently favored generalized tokens in these conditions, whereas a fourth pigeon consistently favored specific tokens.

What accounts for the consistent preference for the generalized tokens in the majority of subjects? One possibility is that stimuli embedded within the token reinforcement schedule contribute to the reinforcing efficacy of the generalized token option, helping create and maintain preference for equally-priced generalized over specific tokens. All token systems can be conceptualized as extended chained schedules (see Hackenberg, 2009), consisting of the following components: (1) token production (contingencies governing token earning); (2) exchange production (contingencies governing the presentation of exchange periods); and (3) exchange (contingencies governing exchange of tokens for terminal reinforcers). Thus, in the present case, (1) pecking the white token production key on the water panel produced a white token and yellow exchange-production key on both panels; (2) pecking the yellow exchange-production key, in turn, produced a flashing white generalized token, signaling an exchange period; and (3) pecking this flashing key, in turn, produced the terminal reinforcer (water or food, depending on the panel on which the exchange response occurred). As stimuli correlated with different links in the chain, the tokens and other correlated stimuli undoubtedly contributed to the coordinated sequences of behavior comprising the token reinforcement performance, as previous research has shown (Bullock & Hackenberg, 2006, 2015; Foster & Hackenberg, 2004; Lagorio & Hackenberg, 2012; Yankelevitz, Bullock, & Hackenberg, 2008).

The present procedures were not designed to distinguish the reinforcing from the discriminative functions of the embedded correlated stimuli; it is likely that both contributed to the results, especially given these pigeons' extensive histories with generalized token reinforcement—histories that predated the present study. These pigeons served previously in the DeFulio et al. (2014) study, along with two additional subjects not part of the present investigation. In that study, five of six pigeons showed consistent preference for the generalized tokens over equally-priced specific tokens, including the three pigeons (999, 271, 113) that preferred the generalized tokens in the present study. Across both studies, in conditions with all else equal (i.e., generalized and specific tokens are equally priced and gain equal access to food and water), relative preference for generalized tokens has been seen in five of six subjects and 32 of 40 conditions. Seven of the eight counterinstances came from the same subject (Pigeon 726), which consistently preferred the specific tokens in both studies. This subject did produce generalized tokens when they could substitute for more expensive specific tokens in price-change conditions, but otherwise consistently preferred specific to generalized tokens. Given the relatively stable choice profiles for each pigeon across studies, it is possible that the preferences for generalized over specific tokens seen in a majority of subjects in the present study reflected preexisting preferences established prior to the experiment. Future research should be directed more closely to the specific histories responsible for individual differences in generalized reinforcing functions.

Because generalized reinforcers derive their efficacy from multiple reinforcers, they must be studied in environments in which they are exchangeable for multiple reinforcers. In most prior research on generalized reinforcement, two reinforcers have been present, but typically only a single motivational operation. For example, the cross-price elasticity effects reported by DeFulio et al. (2014), in which generalized tokens came to substitute for specific tokens, were from conditions in which *either* (a) food was restricted but water was available outside the sessions; or (b) water was restricted but food was available outside the sessions—but not both. In these types of semi-closed environments, evidence of generalized functions comes from deprivation-specific patterns of generalized token production and exchange (i.e., generalized tokens produced and exchanged for the restricted reinforcer).

The present study utilized a more fully closed economy, designed to minimize interactions with extraexperimental contingencies, and maximize control by contingencies with the token economy. The robust and systematic patterns of token production and exchange are due in part to this closed economy, in which all food and water intake occurred within the experimental sessions. This is not the first time this type of closed economy has been used in research on generalized reinforcement (Tan & Hackenberg, 2015, Experiment 3), but is the first time it been examined as such (i.e., as an independent variable). The importance of this variable was clearly demonstrated in the comparisons to the *Open economy* conditions in Phase 2, with free access to food and water outside the sessions. Token production and exchange grew weak in the open economy, with the abundance of substitutable reinforcers available outside the session, showing the critical importance of the economy as a determinant of token performance. The present study included only the extreme ends of the continuum, however, where the economy was either completely closed or completely open. Future research should explore other parts of the continuum, and should also expand the economy to include more than two reinforcers.

The results from the *No-token* conditions in Phase 2 may cast doubt on the functional role of the tokens in the overall performance, as responding was maintained at nearly comparable levels without the tokens. A few caveats are in order, however. First, the tokens are only one of several stimuli embedded within the chain schedule, as discussed previously. As stimuli correlated with the initial link, however, tokens would be expected to exert less control than the exchange-production and exchange stimuli, correlated more directly with the terminal reinforcers. In the *No-Token* conditions, the tokens were removed but the exchange-production and exchange stimuli were not. Such stimuli, temporally proximal to the terminal reinforcers, may be sufficient to maintain responding without strong support of the tokens in these conditions, especially after such extensive histories on these basic procedures. Second, the small exchange-production requirement (FR 1) does not promote strong reinforcing or discriminative functions of the tokens. Such functions stand out more clearly under extended exchange-production schedules (Bullock & Hackenberg, 2015; Yankelevitz et al., 2008). And finally, these conditions were studied in the context of an open economy, in which the value of food (and food-correlated stimuli) was low. Future research should explore further the stimulus functions of the tokens under more expanded motivational conditions and schedule types.

In conclusion, the present study adds to a growing body of research on generalized reinforcement functions in token economies with pigeons. Token economies are well suited to exploring generalized reinforcement functions, providing structured ways to arrange and analyze token production and exchange across various contingencies and motivational conditions. In this way, token economies provide a useful context for the continued cross-fertilization of concepts and methods from behavior analysis and behavioral economics. The present analysis borrows from both frameworks: From behavioral economics it borrows the concepts of substitutability (which accounts well for most of the data under price-change conditions) and economy type (which accounts well for the data under closed vs. open economy conditions); and from behavior analysis it borrows local behavioral mechanisms such as conditioned reinforcement and discriminative control (which together account well for most of the data from price-constant conditions). Bringing these different concepts and methods together in the context of a fully closed token economy with multiple reinforcers and motivational conditions, promises to yield important advances in a comprehensive analysis of generalized reinforcement.

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