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THE TRANSITIVITY OF CHOICES BETWEEN DIFFERENT RESPONSE REQUIREMENTS

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This experiment tested the transitivity of hens' choices between response requirements differing in both form and number. In a concurrent second-order schedule procedure, 6 hens chose between two alternatives by making either key-peck or door-push responses. The reinforcement rates on the two alternatives remained constant and equal throughout conditions, but the number of responses (i.e., key pecks or door pushes) required on each alternative was varied by changing the second-order (fixed-ratio) requirements. The preferences obtained from two pairings of response requirements allowed prediction of the preferences expected in a third pairing. No intransitivities were found, implying that the response requirements lie on a common unitary scale of value. For response-based measures, the obtained preferences varied evenly around perfect, multiplicative prediction, and all satisfied strong transitivity, implying an underlying interval scale of value. For time-based measures, only moderate transitivity was satisfied, implying only an ordinal scale of value. Time-based measures were confounded with the differing times taken to complete each response requirement. The existence of such scales indicates that direct comparisons of different response requirements may be possible.

Key words: transitivity, choice, second-order schedules, key peck, door push, hen

In common parlance the statement "I prefer apples to bananas" can be taken to imply that, given the choice, I will select apples more often than I select bananas, but occasionally I may select bananas. An estimate of the size of my preference could come from observing such choices and by summarizing them as a ratio, a proportion, or a probability. The further statement "I prefer apples to bananas and bananas to cherries" can be taken to imply that I will prefer apples to cherries (i.e., that preference is transitive). The size of the preference I show for apples over cherries in relation to the other two preferences defines the degree of transitivity found, and this determines how precisely one can predict untested choices. Underlying these deductions, particularly that of transitivity, is an implicit assumption that preference is not necessarily exclusive and is measured on a unitary scale, requiring only one dimension of measurement.

Although the existence of a unitary scale of value for outcomes has been the subject of much theoretical writing (e.g., Luce, 1959; Navarick & Fantino, 1974), little is known about the values of different ways of achieving the same outcome. In other words, how do preferences among different behavior requirements leading to the same outcome relate to each other? For example, can the statement "I prefer driving to work to riding a bus, but I prefer riding a bus to cycling" be predictive in any way of the preference I may show for driving over cycling to work? The question is, then, whether a unitary scale of value can apply to ranking different paths to the same goal, in a similar fashion to ranking the value of different outcomes.

Transitivity

Theoretical writing relevant to the quantitative scaling of preferences between outcomes comes from decision theory. Two assumptions are made within decision theory when predicting choices between various outcomes. First, it is assumed that an organism, in making a choice, assigns each item a fixed *subjective value* or *utility* on a single dimension (Krantz, 1967). Second, it is assumed that the probability of choosing one alternative over another is a monotonic function of their respective values. Confirmation of these two assumptions satisfies a choice model known as

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simple scalability (Krantz, 1967). In such a model, each item in a set of choice alternatives can be assigned a value that is invariant with respect to context. Thus, for a two-alternative choice situation, the probability of choosing one item over another is $p(\mathrm{A, B}) = F(\mu_\mathrm{A}, \mu_\mathrm{B})$, where $p(\mathrm{A, B})$ represents the probability that A will be chosen over B, μ_A and μ_B represent the values of A and B, and F is a monotonic function relating choice probability to value. F assumes that, when μ_B remains constant, $p(\mathrm{A, B})$ increases monotonically with increases in μ_A, and when μ_A remains constant, $p(\mathrm{A, B})$ decreases monotonically with increases in μ_B (Tversky & Russo, 1969).

The twin assumptions of unidimensionality and monotonicity that are implicit in simple scalability can be tested by examining the degree to which choices are transitive. The choice proportions obtained in three pairwise combinations of alternatives (triads) are used in transitivity analyses. Transitivity may be found at various levels. Stated formally, when $p(\mathrm{A, B}) \geq .5$ and $p(\mathrm{B, C}) \geq .5$, where $p(\mathrm{A, B})$, $p(\mathrm{B, C})$, and $p(\mathrm{A, C})$ are the probabilities of choosing the first item over the second [i.e., when A is chosen more often than B, say 70% more or $p(\mathrm{A, B}) = .7$, and B is chosen more often than C, say 60% more or $p(\mathrm{B, C}) = .6$], then choice proportions would conform to *weak stochastic transitivity* (WST) if $p(\mathrm{A, C}) \geq .5$ (i.e., if A is simply chosen more often than C), *moderate stochastic transitivity* (MST) if $p(\mathrm{A, C}) \geq \min\,[p(\mathrm{A, B}), p(\mathrm{B, C})]$ (i.e., if A is chosen over C by at least as much as the smaller of the A over B or B over C proportions or, in this case, .6), or *strong stochastic transitivity* (SST) if $p(\mathrm{A, C}) \geq \max\,[p(\mathrm{A, B}), p(\mathrm{B, C})]$ (i.e., if A is chosen over C by as much as the larger of the A over B or B over C proportions or, in this case, .7).

Confirmation of weak or moderate stochastic transitivity validates only the unidimensionality assumption of simple scalability (Luce & Suppes, 1965). Thus, if at least WST is satisfied, the stimuli can be ordered, but not quantified, on a common scale. Such ordinal scales are useful because the direction of preference between any pairs of items can be predicted from the relative magnitudes of their scale values. Violations of WST [*intransitivity*; $p(\mathrm{A, C}) < .5$] indicate that choices between different pairs of items are a function of more than one dimension of the stimuli (Tversky, 1969). Intransitive preference implies that an ordinal utility scale does not exist and that the prediction of choice probabilities is impossible (Navarick & Fantino, 1974).

Confirmation of strong stochastic transitivity guarantees both assumptions of simple scalability. This, in turn, implies that not only does ordinal preference (WST) hold, but that quantitative measures of value can be assigned to each choice item on a common scale. Further, both the directions and magnitudes of the preferences between pairs of items can be predicted from their relative scale values. In other words, the difference between WST and SST is qualitatively similar to the difference between an ordinal and an interval scale.

Several strengthened versions of strong stochastic transitivity have been proposed. Tversky and Russo (1969) designated three of these as *strict stochastic transitivity, independence,* and *substitutability*. Strict stochastic transitivity is essentially equivalent to strong stochastic transitivity except that strict inequality in both hypotheses entails strict inequality in conclusion. Thus, $p(\mathrm{A, B}) > .5$ and $p(\mathrm{B, C}) > .5$ imply $p(\mathrm{A, C}) > .5$. Independence is defined as $p(\mathrm{A, C}) \geq p(\mathrm{B, C})$ implies $p(\mathrm{A, D}) \geq p(\mathrm{B, D})$. Thus, if two choices are ordered according to a given standard, then that ordering must be maintained for an arbitrary standard. Substitutability is the last strengthened version of SST discussed by Tversky and Russo (1969); Navarick and Fantino (1974) called it *functional equivalence*: $p(\mathrm{A, C}) > p(\mathrm{B, C})$ implies $p(\mathrm{A, B}) > .5$ and $p(\mathrm{A, C}) = p(\mathrm{B, C})$ implies $p(\mathrm{A, B}) = .5$. In other words, two items between which an organism is indifferent can substitute for each other in different contexts.

The strictest version of strong stochastic transitivity is the *product rule* (Luce & Suppes, 1965) or *perfect transitivity* (Matthews, 1983):

$$\frac{p(\mathrm{A, C})}{p(\mathrm{C, A})} = \frac{p(\mathrm{A, B})}{p(\mathrm{B, A})} \cdot \frac{p(\mathrm{B, C})}{p(\mathrm{C, B})}. \tag{1}$$

This equation reduces in ratio terms to

$$(\mathrm{A/C}) = (\mathrm{A/B}) \cdot (\mathrm{B/C}), \tag{2}$$

where A/C, A/B, and B/C are the ratios of the frequencies of choosing the pairs of items. Confirmation of perfect transitivity implies that the magnitudes of the preferences between pairs of items can be predicted precisely from an algebraic combination of their scale values. Hence, all triads satisfying perfect transitivity also satisfy all forms of SST, but the opposite is not necessarily true.

Animal Choices

A similar analysis can be applied to the study of animal preferences. These studies frequently use concurrent schedules wherein two or more schedules of reinforcement are simultaneously available. Animals' performances under concurrent schedules have been shown to be a function of reinforcement rate, quality, and amount (e.g., Davison & McCarthy, 1988), and are well described by the generalized matching law (Baum, 1974):

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left(\frac{r_1}{r_2}\right) + \log c, \qquad (3)$$

where B refers to the behavioral measure (responses made or times spent), r refers to the reinforcers obtained, and the subscripts denote two alternatives. The parameter a describes the sensitivity of behavior to reinforcement-rate differences, and the parameter c, termed bias, measures any constant preference for one alternative, over and above reinforcement-rate differences (Baum, 1974, 1979). Under this model, individual instances of behavior on one or another schedule (which may be regarded as individual choices) are not predicted, but the aggregate over some period of responding is. Hence, measures of concurrent-schedule performance may be taken as estimates of probability for transitivity analyses.

Concurrent behavior measures are usually given as ratios (Baum, 1974). As shown in the generalized matching law, these ratios are directly related to, and determined by, the ratios of the measures of the environmental events (e.g., reinforcer parameters). The probability measure of .5 corresponds to a ratio of 1.0. The probability measure of 1.0 corresponds to infinity in ratio form, and represents exclusive choice.

In order to understand the various degrees of transitivity in ratio terms, consider again offering a subject the choice between two pairs of fruit: apples (A) and bananas (B) and bananas (B) and cherries (C). Say he or she chooses, on average, apples twice as often as bananas (A/B = 2), and he or she chooses bananas three times more often than cherries (B/C = 3). If the subject is then offered a choice between the two fruits not previously paired—apples (A) and cherries (C)—then for WST to be satisfied, the subject must choose apples at least as often as he or she chooses cherries (A/C ≥ 1.0). For MST to be satisfied, the subject must choose apples at least as often as he or she chose apples over bananas (i.e., because the smaller preference A/B = 2, then A/C must be ≥ 2). For SST to hold, the subject must choose apples at least as often as he or she chose bananas over cherries (i.e., because the larger preference B/C = 3, then A/C must be ≥ 3). For perfect transitivity to be confirmed, the subject must choose apples exactly six times more than cherries (A/C = 6.0).

In the case of a choice between rates of reinforcement, it seems reasonably established, through the generalized matching law, that preferences between pairs of rates of reinforcement will satisfy perfect transitivity. For example, consider behavior under three pairs of concurrent variable-interval (VI) VI schedules: VI 30 s versus VI 60 s, VI 60 s versus VI 120 s, and VI 30 s versus VI 120 s. Assuming that the parameters a and c remain constant, then performance in the third pairing is predicted, by substitution of the relevant variables in Equation 3, to be the product of the other two preferences. This suggests that in most cases rate of reinforcement has a unitary scale of value.

Whether such a unitary scale of value exists for other parameters such as food quality is less clear, but this has been examined by several researchers (e.g., Matthews, 1983; Miller, 1976). These researchers have generally assessed preference between two pairs of food types (e.g., A vs. B and B vs. C) using equal concurrent VI VI schedules and measuring the resulting bias ratios (log c measures, Equation 3). These bias or preference ratios were then used to predict the bias measures expected when A and C were themselves paired. Miller, studying pigeons and their choices between three types of grain, concluded that average response and time preference measures could be predicted with reasonable accuracy, but that individual prediction was not good. Matthews, studying cows' choices between six silages and a standard feed (barley), concluded that both the individual-subject and average response-based preference measures allowed good prediction of both the magnitude and direction of the preferences resulting from subsequent pairings, but the time-based measures did not.

Behavior under concurrent schedules can also show changes in bias (i.e., in preference) when different response requirements, rather than different reinforcers, are used. The prediction and scaling of different reinforcers, outlined above, may allow a method for quantifying and predicting the effects of different responses. That is, if the preference ratios produced by pairing responses A versus B and B versus C were known, then the response and time preference measures produced by pairing A versus C might be predicted.

As argued by Sumpter, Temple, and Foster (1998), response and time measures will change differently with qualitative and quantitative changes in response requirements, because of the differing times required to complete those requirements. However, even though the numbers (i.e., bias measures) will be different, either measure should be capable of predicting the preference expected in a third combination of response requirements from the results of two previous combinations. For example, suppose that 50 A responses take 50 s, 100 B responses take 200 s, and 150 C responses take 450 s, and that these correspond to the actual numbers of responses recorded when they are paired on equal concurrent schedules. The preference ratios resulting from pairing A with B will be approximately .5 in terms of response completions and .25 in terms of times. Those resulting from pairing B with C will be .67 in response completions and .44 in terms of time measures. Thus, if multiplicative prediction is assumed, then predicting the A/C bias ratios (i.e., $A/C = A/B \times B/C$) should give .33 for response measures and .11 for times. That is, both predictions are possible, but they will differ.

Response-based scales would be useful on a number of accounts. First, the preferences between new pairs of response requirements could be predicted from their scale values. Second, analyses of responses with similar scale values may lead to the identification of factors that give rise to bias, such as the time or effort needed to emit the response.

Only one attempt has been made to predict and construct scales of preferences for different response requirements. Using hens as subjects, Sumpter, Foster, and Temple (1995) used the average bias estimates obtained when the response requirements of five key pecks and one door push were each paired with a key peck in order to predict the relative biasing effects of five key pecks versus a door push. These predictions were then compared to the bias measures actually obtained when the door-push and fixed-ratio (FR) 5 (key-peck) requirements were paired. Although the predictions were not perfect, they were in accord with the obtained preference ratios (for both responses and times).

Sumpter et al. (1995) then used the average bias estimates obtained in all parts of their experiment to construct a scale of the relative preferences for the different responses. As Miller (1976) suggested, this was done by assigning an arbitrary value of 10 units to the value of one key peck. When the average response bias estimates were used, the FR 5 and door-push requirements were found to have scale values of 1.78 and 2.19, respectively. Hence, both responses appeared to have around one fifth the value of a key peck, or may be thought of as requiring five times the effort. Using the average time bias measures, scale values of 7.4 and 3.5 were found for an FR 5 requirement and a door push, respectively. Thus, the scales based on response and time measures did not agree, because scales based on response completion and time measures will differ when different operants that necessarily take different times to complete are used (Sumpter et al., 1995, 1998).

It remains to be determined, however, whether the generalized matching law can be used to scale and predict hens' preferences between large response-requirement differentials. Sumpter et al. (1998) argued that larger FR requirements affect obtained reinforcer frequency to a greater extent than small FR requirements do and may, therefore, alter sensitivity to reinforcer rate even when relative reinforcement rates are controlled. Their results also showed that responding under concurrent second-order schedules does not reflect a fixed maximum response rate when large FR requirements are used as the first-order operants. Rather, the response rates vary both across and within comparisons. This raises questions regarding the utility of the generalized matching law in the prediction and scaling of response requirements that differ considerably in size. Equally, little is known about predicting and scaling across different response topographies.

The data obtained by Sumpter et al. (1998) were not collected with the above predictions in mind. They would, however, form part of a set of conditions suitable for predicting and scaling topographically and numerically different responses if other data were to be gathered.

Sumpter et al. (1995, 1998) presented data from hens responding on concurrent VI VI schedules using different response requirements differing in both form (i.e., key peck and door push) and in the number of individual responses making up a response unit (i.e., second-order FR requirements). The present experiment was conducted in order to extend Sumpter et al.'s (1995) research on the prediction and scaling of different responses by increasing the range of FR requirements associated with the different response forms. Five of the hens and all of the equipment used by Sumpter et al. (1995) and all of the hens and equipment used by Sumpter et al. (1998) were still available for use in the present study. The hens were exposed to four pairs of response requirements on equal concurrent second-order schedules of reinforcement. The data from these conditions were combined with some of the data obtained in Sumpter et al.'s (1995) experiment (with all but one of the hens as here) and some from Sumpter et al.'s (1998) first experiment (with all hens as here). The resulting response and time bias measures could be arranged into three triads of pairwise comparisons suitable for the prediction and scaling of choices between responses differing in number and form. An assessment of the degree of transitivity found across the three triads of choices was also made.

METHOD

Subjects

Six Shaver-Starcross hens, numbered 61 to 66, were maintained at 80% (±5%) of their free-feeding body weights by daily weighing and supplementary feeding (commercial laying pellets). They were housed in individual cages (30 cm by 45 cm by 43 cm) with water freely available. Grit and vitamins were supplied weekly. All hens were approximately 5 years old at the start of the experiment. All hens had served in Sumpter et al.'s (1998) study and, with the exception of Hen 66, in Sumpter et al.'s (1995) study. In doing so, they all had experience on concurrent second-order VI (key-peck) VI (door-push) schedules of reinforcement.

Apparatus

In Conditions 1 and 2 of the present experiment the apparatus was identical to that used in the earlier experiments (Sumpter et al., 1995, 1998). The particle-board experimental chamber was 57 cm long, 42 cm wide, and 54 cm high. A thick metal grid enclosed in a steel tray covered the floor, and a fan in the rear wall provided air circulation and masking noise. A food magazine, which was lit and allowed access to wheat when raised, was located directly behind an opening centered on the front wall 8.5 cm above the top of the grid floor. The front wall also contained a translucent plastic key and a door manipulandum. The key, 3 cm in diameter, was situated 9.5 cm from the left wall and 36 cm above the floor. It required a minimum force of 0.1 N (11 grams-force) to be activated and, when operative, was lit from behind by a red 1-W bulb. The door was located 2 cm from the right wall and had its top 37 cm from the grid floor. It consisted of two vertical brass rods (through which the hens could push their heads and necks) which, when suspended, hung 4 cm inside the front wall and 10 cm above the grid floor. In order for an effective door push to be made, these rods needed to be pushed 5 cm forward (measured at the bottom of the rods), or to an angle of 15°. This movement operated a microswitch and required a minimum force of 1.1 N (112 grams-force; measured 4 cm from the bottom of the rods) when no weights were attached to the door. Obviously, the height at which the door was pushed could vary both within and between conditions, but measuring the force requirement 4 cm from the bottom of the rods provided at least an approximation.

So that the hens did not hit the front wall when the rods were pushed to an angle of 15°, a hole (10 cm by 19 cm) was cut out of the front wall directly below the door frame and 11 cm from the floor. A box (10 cm wide, 18 cm deep and 29 cm wide) was fixed to the rear of the front wall so that it covered the hole. This meant that the hen's head would be in this box when an effective door push was made. A 1-W white bulb located at the rear of this box provided illumination of the door apparatus.

For Conditions 3 and 4, the experimental chamber was modified to include two response keys. The door was removed, and the hole was covered with sheet metal. A translucent plastic response key was fixed onto this, 36 cm above the floor and 17 cm from the existing key. Both keys were 3 cm in diameter, required a minimum force of 0.1 N (11 grams-force) to be activated, and could be lit from behind by a red 1-W bulb. The manipulanda lights and the magazine lights provided the only sources of illumination in the chamber. The equipment was controlled and the data were recorded by a computer operating MED™ 2.0 software.

Procedure

All birds were exposed to a series of concurrent second-order schedules of reinforcement, with completions of FR requirements reinforced according to equal VI 90-s VI 90-s schedules. The VI schedules were arranged dependently and were composed of 15 randomized intervals that were derived from the arithmetic progression $j + kx$, where $x = 0, 1, 2, \ldots, 14$, j is equal to one 15th of the average VI length, and $k = 2j$.

The response requirement pairings employed during the four conditions of the experiment were FR 1 (key) versus FR 3 (door), FR 15 (key) versus FR 1 (door), FR 1 (key) versus FR 1 (key), and FR 1 (key) versus FR 15 (key). In each condition, the first response of each FR requirement (which could be emitted to either manipulandum) extinguished the alternative manipulandum light and rendered that manipulandum inoperative. On completion of the ratio requirement, and provided that a reinforcer associated with that manipulandum had been set up by the VI schedule, a reinforcer was delivered. Following reinforcement or the completion of the FR requirement, both manipulanda lights were again presented.

Table 1

The sequence of experimental conditions. Shown are the response types, the FR and VI schedules employed, and the number of days each condition was in effect for all 6 subjects.

Condition	Response types		FR schedules		VI Schedules (s)		Sessions
	Left	Right	Left	Right	Left	Right	
1	key	door	1	3	90	90	21
2	key	door	15	1	90	90	26
3	key	key	1	1	90	90	32
4	key	key	1	15	90	90	37

In all conditions, each effective (i.e., first-order) response was signaled to the subject by a short (30 ms) audible beep, whereas the completion of each FR (second-order) requirement was signaled by a longer (400 ms) audible beep. Reinforcement consisted of 3-s access to wheat if initiated by an FR completion on the key and 3.5-s access to wheat if initiated by an FR completion on the door. This gave the hens enough time to move back from the door and still get approximately 3-s access to the reinforcer. During reinforcement, the manipulanda lights were extinguished. Responses to unlit manipulanda were ineffective.

All experimental sessions ended after 30 reinforcers or 40 min (whichever was the shorter), and at least six sessions were conducted per week. The experimental conditions were changed when the behavior of all subjects had reached a stability criterion five, not necessarily consecutive, times. The criterion was that the median relative number of responses (i.e., total number of pecks on the left key divided by the total number of responses made on both manipulanda) over the last five sessions was within 0.05 of the median of the previous five sessions. Table 1 shows the sequence of experimental events along with the number of sessions each condition was in effect for all birds.

RESULTS

The averaged log FR completion and log time-allocation ratios from the last five sessions of each condition were analyzed here. The individual data collected during those fi-

Table 2

The logarithms of the FR completion and time bias estimates averaged across the last five sessions of each condition are presented for the individuals and for the group. The standard errors of the bias estimates (in parentheses) are also shown. The preference measures presented for Condition 4 have been corrected for position bias. k indicates key pecks, d indicates door pushes, and the number indicates the requirement for a unit.

	Condition			
Hen	1 1k vs. 3d	2 15k vs. 1d	3 1k vs. 1k	4 1k vs. 15k
FR completions				
61	1.36 (0.05)	−0.43 (0.06)	−0.12 (0.18)	1.38 (0.07)
62	0.71 (0.02)	−0.72 (0.05)	0.00 (0.05)	0.91 (0.10)
63	0.93 (0.04)	−0.58 (0.08)	0.27 (0.03)	0.71 (0.05)
64	1.56 (0.04)	−0.48 (0.08)	0.00 (0.02)	1.00 (0.04)
65	1.61 (0.05)	−0.11 (0.08)	0.16 (0.02)	0.99 (0.03)
66	0.87 (0.12)	−0.74 (0.06)	0.17 (0.04)	1.05 (0.03)
M	1.17 (0.05)	−0.51 (0.07)	0.08 (0.06)	1.01 (0.05)
Times				
61	0.64 (0.04)	0.44 (0.07)	−0.12 (0.10)	0.42 (0.05)
62	−0.06 (0.02)	−0.10 (0.04)	0.02 (0.09)	0.09 (0.08)
63	0.05 (0.02)	0.16 (0.08)	0.16 (0.02)	0.24 (0.03)
64	0.61 (0.04)	0.31 (0.03)	−0.01 (0.02)	−0.02 (0.03)
65	0.50 (0.07)	0.34 (0.06)	0.14 (0.04)	0.09 (0.03)
66	−0.01 (0.05)	−0.12 (0.03)	0.14 (0.04)	−0.02 (0.02)
M	0.29 (0.04)	0.17 (0.05)	0.06 (0.05)	0.13 (0.04)

nal sessions are presented in the Appendix. All ratios were taken to the left alternative and were transformed into logarithmic measures (to the base 10). The time measures were based on the interchangeover times. Unless otherwise stated, every completion of each FR requirement was regarded as an operant and was treated as a response unit in these analyses.

Estimates of key bias were derived from the behavior measures recorded in Condition 3 [FR 1 (key) FR 1 (key)]. The response-unit (i.e., FR completion) and time bias estimates obtained in Condition 4 [FR 1 (key) FR 15 (key)] were then corrected for this position bias using the procedure outlined by Matthews and Temple (1979). For the individual logarithmic measures, this involved subtracting the bias estimates obtained in Condition 3 from those obtained in Condition 4. Such correction was possible only for data from the concurrent key-peck key-peck condition. The magnitudes of the position bias estimates (log *c*) found during that condition were small and similar for both response ($M = 0.08$) and time ($M = 0.06$) measures.

The means (i.e., the averages across the last five sessions) and standard errors of the individual response-unit and time bias measures are presented for all conditions in Table 2. The preference measures for Condition 4 are those corrected for position bias as described above. The logarithms of the ratios of the reinforcers obtained on the two alternatives were also calculated and were close to 0. The standard errors of the individual response-unit and time bias measures were small and similar. This indicates that there was little uncontrolled day-to-day variation within the individual data on each comparison.

Together with the data from two of Sumpter et al.'s (1995) conditions and two conditions from Sumpter et al.'s (1998) first experiment, three of the comparisons here provided preference measures for seven possible pairwise combinations of different response requirements for individual hens. The bias estimates used from Sumpter et al.'s (1995) experiment were those derived from the best fit lines describing the data obtained during the FR 1 (key) versus FR 5 (key) and FR 5 (key) versus FR 1 (door) pairings. Those included from Experiment 1 of Sumpter et al.'s (1998) study were derived from the lines fitting the data obtained during the FR 1 (key) versus FR 1 (door) and FR 15 (key) versus FR 3 (door) conditions. The seven conditions can be arranged into three triads of pairwise comparisons suitable for the prediction of choice. These triads, together with the logarithms of the obtained preference ratios, are shown in Table 3 for both the individual response-unit and time measures and for the group means (i.e., arithmetic means of the individual log ratios). To make triad comparisons possible, it is necessary to arrange the three responses in each triad so that all comparisons (i.e., bias measures) are positive in sign. Hence, the ordering of the pairwise comparisons within each triad differs across hens. Because Hen 66 was not employed during Sumpter et al.'s (1995) experiment, her data were excluded from any analyses that required the data from the FR 1 (key) versus FR 5 (key) and FR 5 (key) versus FR 1 (door) comparisons (e.g., the data in the first triad of pairwise combinations of response requirements).

Table 3

The triads of pairwise choices and the associated bias (log *c*) estimates calculated from seven binary comparisons for individual hens. The triads are arranged so that all comparisons are positive in sign. k and d indicate key pecks and door pushes, respectively.

Hen	Triads	Log *c*	Triads	Log *c*	Triads	Log *c*
FR completions						
61	1k/1d[a]	0.54	1k/1d[a]	0.54	1k/3d	1.36
	1d/5k[b]	0.08	1d/15k	0.43	3d/15k[a]	0.00
	1k/5k[b]	0.57	1k/15k	1.38	1k/15k	1.38
62	1k/1d[a]	0.19	1k/1d[a]	0.19	1k/3d	0.71
	1d/5k[b]	0.25	1d/15k	0.72	3d/15k[a]	0.21
	1k/5k[b]	0.74	1k/15k	0.91	1k/15k	0.91
63	1k/1d[a]	0.96	1k/1d[a]	0.96	15k/3d[a]	0.02
	1d/5k[b]	0.00	1d/15k	0.58	1k/15k	0.71
	1k/5k[b]	1.01	1k/15k	0.71	1k/3d	0.93
64	1k/5k[b]	0.72	1k/1d[a]	0.87	1k/3d	1.56
	5k/1d[b]	0.14	1d/15k	0.48	3d/15k[a]	0.03
	1k/1d[a]	0.87	1k/15k	1.00	1k/15k	1.00
65	1k/1k[a]	0.56	1k/1d[a]	0.56	1k/3d	1.61
	1d/5k[b]	0.01	1d/15k	0.11	3d/15k[a]	0.16
	1k/5k[b]	0.79	1k/15k	0.99	1k/15k	0.99
66	1k/1d[a]		1k/1d[a]	0.56	1k/3d	0.87
	1d/5k[b]		1d/15k	0.74	3d/15k[a]	0.03
	1k/5k[b]		1k/15k	1.05	1k/15k	1.05
M	1k/1d[a]	0.59	1k/1d[a]	0.61	1k/3d	1.17
	1d/5k[b]	0.01	1k/15k	0.51	3d/15k[a]	0.07
	1k/5k[b]	0.80	1k/15k	1.01	1k/15k	1.01
Times						
61	5k/1k[b]	0.07	1k/15k[a]	0.42	1k/15k	0.42
	1k/1d[a]	0.29	15k/1d	0.44	15k/3d[a]	0.24
	5k/1d[b]	0.23	1k/1d[a]	0.29	1k/3d	0.64
62	1k/5k[b]	0.05	1k/1d[a]	0.06	1k/15k	0.09
	5k/1d[b]	0.06	1d/15k	0.10	3d/1k	0.06
	1k/1d[a]	0.06	1k/15k	0.09	3d/15k[a]	0.14
63	1k/5k[b]	0.43	1k/15k[a]	0.24	1k/15k	0.24
	5k/1d[b]	0.35	15k/1d[a]	0.16	15k/3d[a]	0.22
	1k/1d[a]	0.51	1k/1d[a]	0.51	1k/3d	0.05
64	1k/5k[b]	0.06	1k/1d[a]	0.67	15k/1k	0.02
	5k/1d[b]	0.32	15k/1k	0.02	1k/3d	0.61
	1k/1d[a]	0.67	15k/1d	0.31	15k/3d[a]	0.35
65	1k/5k[b]	0.27	1k/15k	0.09	1k/15k	0.09
	5k/1d[b]	0.32	15k/1d	0.34	15k/3d[a]	0.03
	1k/1d[a]	0.19	1k/1d[a]	0.19	1k/3d	0.50
66	1k/5k[b]		1d/15k	0.12	15k/3d[a]	0.24
	5k/1d[b]		15k/1k	0.02	3d/1k	0.01
	1k/1d[a]		1k/1d[a]	0.49	15k/1k	0.02
M	1k/5k[b]	0.18	1k/15k	0.13	1k/15k	0.13
	5k/1d[b]	0.27	15k/1d	0.17	15k/3d[a]	0.15
	1k/1d[a]	0.33	1k/1d[a]	0.37	1k/3d	0.29

[a] Sumpter et al. (1998, Experiment 1).

[b] Sumpter et al. (1995). Hen 66 was not used.

The biases expected to result from the third pairwise comparison in a triad can be predicted from the bias estimates obtained in the former two response-requirement pairings in that triad (perfect transitivity condition, Equation 2). For example, the bias expected in the combination FR 1 (key) versus FR 5 (key) can be derived from the FR 1 (key) versus FR 1 (door) and FR 1 (door) versus FR 5 (key) biases. Specifically, it is the first log *c* estimate in each triad plus the second. These predicted response-unit and time bias (log *c*) estimates are presented in Table 4, together with the obtained bias estimates and the standard errors of the obtained values. From Table 4 it can be seen that the response-unit and time ratios were predicted with similar inaccuracy. Only six (35%) of the individual response-unit predictions and three (17%) of the time predictions were within one standard error of estimate of the obtained values.

Figure 1 shows the predicted log *c* estimates from Table 4 (predicted on the basis of perfect transitivity) plotted against the obtained log *c* estimates. If the obtained values were the same as the predicted values, the data would fall on the lines of unit slope. Clearly, neither the response nor time measures fall exactly on these lines (*SE* = 0.37 and 0.29, respectively). It can be seen that the

Table 4

The predicted log FR completion and time bias values are presented for the third pairing of response requirements in each triad, together with the obtained values and the standard errors of the estimates of the obtained values. k and d indicate key pecks and door pushes, respectively.

	FR completions				Times			
Hen	Pair	Predicted	Obtained	*SE*	Pair	Predicted	Obtained	*SE*
Triad 1								
61	1k/5k	0.62	0.57	0.07	5k/1d	0.36	0.23	0.09
62	1k/5k	0.44	0.74	0.12	1k/1d	0.11	0.06	0.00
63	1k/5k	0.96	1.01	0.05	1k/1d	0.78	0.51	0.07
64	1k/1d	0.86	0.87	0.09	1k/1d	0.38	0.67	0.09
65	1k/5k	0.57	0.79	0.11	1k/1d	0.59	0.19	0.07
66	1k/5k				1k/1d			
Triad 2								
61	1k/15k	0.97	1.38	0.07	1k/1d	0.86	0.29	0.06
62	1k/15k	0.91	0.91	0.10	1k/15k	0.16	0.09	0.08
63	1k/15k	1.54	0.71	0.05	1k/1d	0.40	0.51	0.07
64	1k/15k	1.35	1.00	0.04	15k/1d	0.69	0.31	0.03
65	1k/15k	0.67	0.99	0.03	1k/1d	0.43	0.19	0.07
66	1k/15k	1.30	1.05	0.03	1k/1d	0.24	0.49	0.11
Triad 3								
61	1k/15k	1.36	1.38	0.05	1k/3d	0.66	0.64	0.04
62	1k/15k	0.92	0.91	0.08	3d/15k	0.15	0.14	0.07
63	1k/3d	0.73	0.93	0.04	1k/3d	0.46	0.05	0.02
64	1k/15k	1.59	1.00	0.03	15k/3d	0.63	0.35	0.13
65	1k/15k	1.77	0.99	0.03	1k/3d	0.12	0.50	0.07
66	1k/15k	0.90	1.05	0.02	15k/1k	0.25	0.02	0.02

individual response predictions are distributed approximately equally above and below the lines of unit slope, and that the high standard error of prediction comes mainly from three outlying points. In contrast, the individual predictions using the time measures tended to be more extreme than the obtained values, as seen by the majority of these data points falling below the lines of unit slope. Least squares best fit lines were also fitted to the behavior measures. These lines (not shown) had low slopes (0.22 for FR completions and 0.25 for times) and large standard errors (0.21 for both measures).

The bias estimates obtained during each response-requirement pairing (Table 3) were used to construct scales of the relative preferences for the different response requirements. In order to construct the scales, one key peck was assigned an arbitrary value of 10. Obviously, any other response requirement could have served, because, despite a different standard, the relative preferences for the response requirements would remain unchanged.

Table 5 presents the response- and time-scale values calculated for each of the response requirements from the individual hens' data and from the group data. For ease of comparison, the rank orders of the scale values are also shown. In the case of Hen 66, the rank orderings of the response requirements are not presented because she was not used in Sumpter et al.'s (1995) experiment and therefore had not been exposed to an FR 5 (key-peck) requirement. Table 5 shows that both the magnitudes and the ordering of the preferences differed when measured in terms of response and time measures. Table 5 also shows that the response requirements were usually ranked similarly in terms of each hen's response-unit measures. This was not the case, however, for the time measures. Thus, only in terms of the response data were the group preferences typical of the individual measures.

Figure 2 presents the response and time preference scales using the group bias estimates. Here, the differences between the response-unit and time scales are highlighted.

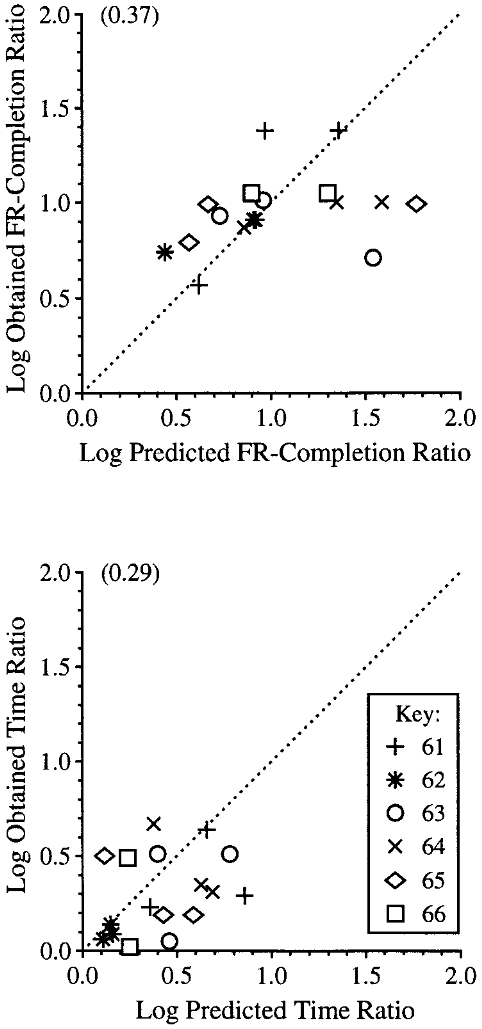

Fig. 1. The obtained response (top panel) and time (bottom panel) ratios for pairs of response requirements plotted as functions of the ratios predicted from an algebraic combination of their preference values in each triad for individual birds. The ratios were taken to the left manipulandum. The dotted diagonal lines represent lines with slopes of 1.0, and the standard errors of estimate of the data from the lines are presented in parentheses.

The scale derived from response measures shows that a response requirement of one key peck was preferred, on average, to the lowest ranked response requirement (i.e., three door pushes) by a factor of 9.3. The time preference scale shows that one key peck was preferred to the lowest ranked response requirement (i.e., one door push) by an average factor of 5.7.

To test the type of transitivity confirmed in each triad (Table 3), the observed preferences were plotted against both the maximum (strong transitivity prediction) and minimum (moderate transitivity prediction) scale values of the two items of a pair. These functions are presented in Figures 3 and 4, respectively, along with the lines of unit slope, which show the lower bound of the predicted ranges. To summarize these results, the frequencies of the different types of transitivity obtained over all individual triads are given in Table 6 for both behavior measures.

There were no consistent differences between individual hens in the degree of transitivity confirmed. Strong transitivity was observed in 14 (82%) of 17 triads using response measures (all but three of the response predictions fall above the line of unit slope, Figure 3) and in 8 (47%) of the triads using time measures (the time predictions are distributed evenly above and below the line of unit slope, Figure 3). Table 6 shows that all triads that satisfied strong transitivity also confirmed strict transitivity, as outlined by Tversky and Russo (1969). In only one of the response triads, however, was perfect transitivity observed. Moderate transitivity was satisfied in all of the response triads and in 14 (82%) of the time triads (as seen by the number of predictions that fall above the lines of unit slope in Figure 4). The three time-allocation triads that did not satisfy at least moderate transitivity did satisfy weak transitivity. There were no instances of intransitivity.

DISCUSSION

These data allow examination of two different sorts of prediction. The first sort of prediction concerns prediction of an exact bias value for a third pairing from the results of two previous pairings (i.e., the perfect transitivity prediction, Equation 1). The second sort involves prediction of a minimum value above which a third pairing will lie (i.e., the lower limit of the predicted interval varies according to the degree of transitivity). When testing predictions of exact values, obtained data that vary evenly around the predictions (i.e., the lines of unit slope in Figure 1) indicate that the predictions are reasonable. Even variation implies that the predictions over- and underestimate approximately

Table 5

The preference scale values (SV) and rank orders (R) of the five response requirements are presented for the individual FR completion and time measures and for the group. The rank orders of the response requirements are not presented for Hen 66 because she was not included in the pairwise comparisons involving the FR 5 (key-peck) requirement conducted by Sumpter et al. (1995).

	Hen 61		Hen 62		Hen 63		Hen 64		Hen 65		Hen 66		Group	
Response	SV	R	SV	R	SV	R	SV	R	SV	R	SV	R	SV	R
FR Completions														
1 key	10.0	1	10.0	1	10.0	1	10.0	1	10.0	1	10.0		10.0	1
1 door	2.9	2	6.5	2	1.1	4	1.3	3	2.8	2	2.8		2.5	2
5 key	2.7	3	1.8	4	1.0	5	1.9	2	1.6	3			1.8	3
15 key	0.4	4.5	1.2	5	1.9	2	1.0	4	1.0	4	0.9		1.0	4
3 door	0.4	4.5	1.9	3	1.2	3	0.3	5	0.2	5	1.3		0.7	5
Times														
1 key	10.0	2	10.0	2	10.0	1	10.0	2	10.0	1	10.0		10.0	1
1 door	5.1	3	8.7	4	3.1	5	2.1	5	6.5	3	3.2		4.3	5
5 key	11.7	1	8.9	3	3.7	4	8.7	3	5.4	4			7.8	2
15 key	3.8	4	8.1	5	5.7	3	10.5	1	8.1	2	10.4		7.4	3
3 door	2.3	5	11.4	1	8.9	2	2.5	4	3.2	5	10.2		5.1	4

equally. Wide variation, however, suggests that the predictions are not precise. In contrast, when predicting a minimum value above which obtained preference values should lie (i.e., predicting varying degrees of transitivity), data that all lie above the minimum predictions confirm that degree of transitivity.

Perfect Transitivity Prediction

Prediction of the first sort (i.e., of particular values) was examined in Figure 1, and it can be seen that although response-completion predictions were variable (mainly the result of three outlying points), they were approximately evenly distributed about the prediction line. Hence, in terms of response measures, prediction of a third pair of response requirements by simply multiplying the two previously found preference ratios may provide the best, albeit not necessarily precise, prediction. Time measures were, however, generally below the line, suggesting that the predictions systematically overestimated the obtained values. The time measures were not predicted as well as the response measures.

The failure to predict the magnitudes of the individual response and time preferences exactly may have resulted from the order in which the different responses were paired. The response and time bias estimates obtained from the FR 1 (key) versus FR 1 (door) condition conducted in Sumpter et al.'s (1995) study tended to be larger than those obtained approximately 3 years later in a replication conducted by Sumpter et al. (1998). The means of the differences between the bias measures, excluding those from Hen 66 (who did not take part in both experiments), were 0.04 and 0.07 for responses and times, respectively. Although this finding suggests that the order of the response pairings may have influenced the results, additional explanations also may be offered. Those explanations are also relevant to the observed differences in the scaling and transitivity of the response-unit and time preference measures, and will be discussed below.

Scaling

In other experiments in which scales of preferences between qualitatively different reinforcers have been constructed (e.g., Klopfer, Kilgour, & Matthews, 1981; Matthews, 1983; Miller, 1976), it is uncommon to observe consistent differences in the ordering of response and time preferences, as occurred in the present study. However, when topographically or numerically different response requirements are employed, scales based on response and time biases would be expected to differ. This is because time allocation is likely to be confounded by the du-

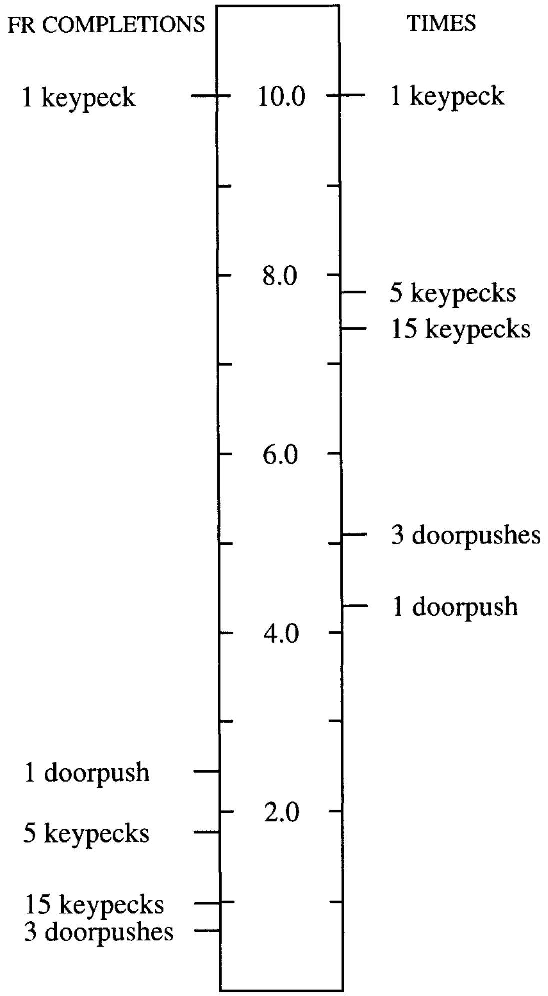

Fig. 2. Scales of the preference values of the response requirements derived from both FR completion and time measures for the group data. The single key-peck requirement served as the arbitrary standard for each scale and was assigned a value of 10 units. The scales are logarithmic.

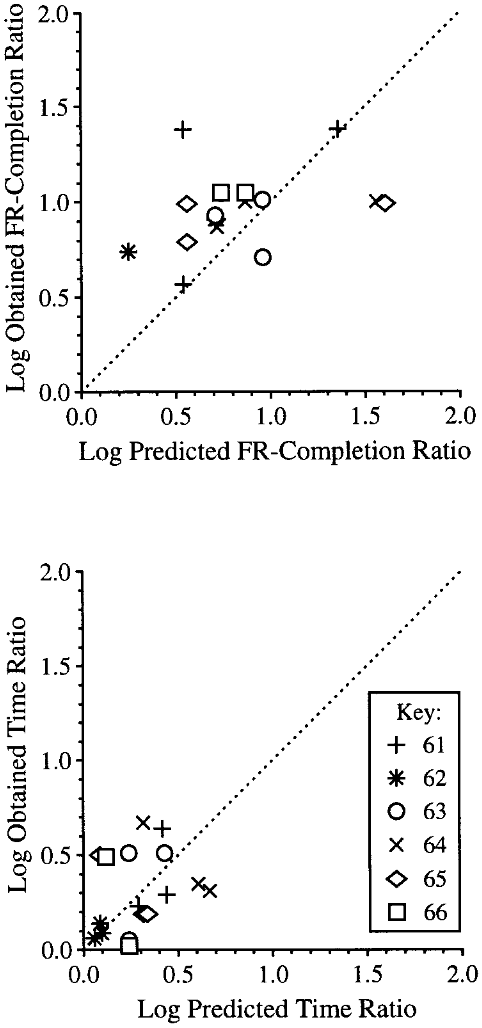

Fig. 3. The obtained response (top panel) and time (bottom panel) ratios for pairs of response requirements plotted as functions of the ratios predicted from the maximum preference values (strong transitivity condition) in each triad for individual birds. The ratios were taken to the left manipulandum. The dotted diagonal lines represent lines with slopes of 1.0.

rations of the responses and the times spent not responding, whereas response measures include only the number of responses made on the two alternatives (Sumpter et al., 1998).

The rank orderings of the response requirements here were similar, although not identical, for the individual animals on response-unit measures. Some variation would be expected because certain individuals may have been "better" at emitting one or the other of the two topographically different responses. In terms of times, the orderings of the preferences were dissimilar across individuals. Individual hens may also have spent differing amounts of time pausing, and therefore taken different times to emit each response unit. On this basis, one would expect individual variation.

Transitivity

In order for the above scaling to have any validity, the data must, at least, have satisfied the requirements of weak stochastic transitivity. This was confirmed in all 17 triads for

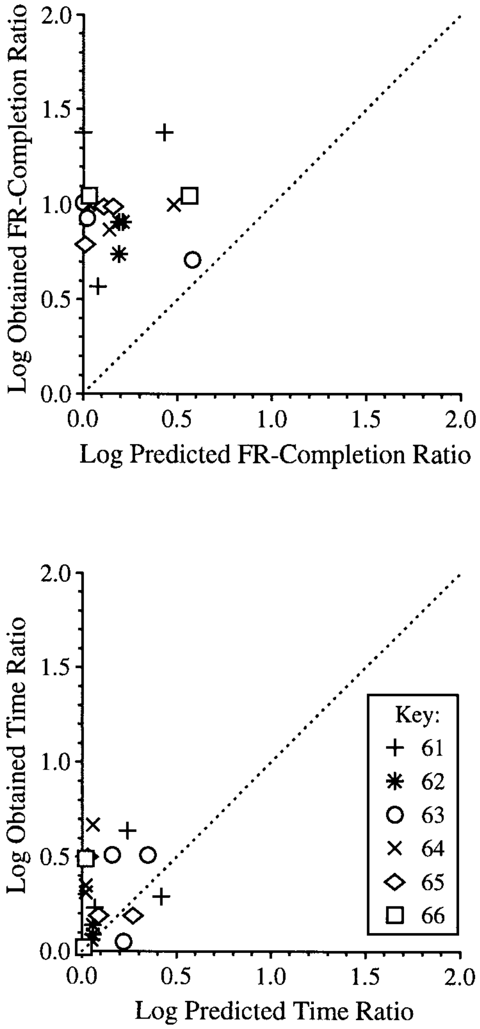

Fig. 4. The obtained response (top panel) and time (bottom panel) ratios for pairs of response requirements plotted as functions of the ratios predicted from the minimum preference values (moderate transitivity condition) in each triad for individual birds. The ratios were taken to the left manipulandum. The dotted diagonal lines represent lines with slopes of 1.0.

Table 6

The frequencies of the different types of transitivity for the preference ratios over all individual triads for both FR completion and time measures. The frequencies of strict transitivity are shown in parentheses.

Transitivity	FR completions	Times
Strong	14 (14)	8 (8)
Moderate	17	14
Weak	17	17
Intransitive	0	0

both response and time measures. These results satisfy the unidimensionality assumption of simple scalability using preference ratios derived from both measures. Along with Miller's (1976) and Matthews' (1983) data on choices between qualitatively different feeds, they suggest that scales derived from preference ratios are valid.

Although predictions using the perfect transitivity condition were reasonable, here, they still varied from the obtained data. Predictions less likely to be wrong may come from using a less restrictive form of transitivity (e.g., strong transitivity) to predict simply an interval in which the obtained preferences may fall, rather than the exact magnitude of those preferences. These predictions were examined in Figures 3 and 4 and Table 6. Strong (and strict) transitivity was satisfied in 82% of the response triads but in only 47% of the time-allocation triads. Therefore, based on these results, predictions based on strong transitivity would be very likely to be satisfied for the response measures but would only be satisfied about 50% of the time for time measures. This, in turn, implies that preference based on response measures is of both an ordinal (directional) and interval (quantifiable) nature, but that only the former applies to preference based on time measures.

The observed response-unit and time biases for the different response requirements were plotted as functions of the minimum biases of the two items of a pair (i.e., moderate transitivity prediction) in Figure 4. This, by using the smaller of the original preferences, predicts a wider range for the preference measures in a third pairing. From Figure 4 it can be seen that moderate transitivity was satisfied in all cases for response measures and in all but three cases for time measures. Clearly this suggests that predictions based on moderate transitivity would rarely be wrong.

In an examination of the transitivity of cows' choices between qualitatively different feeds, Matthews (1983) reported that strong and strict transitivity were confirmed using response measures, but that only weak transitivity was satisfied using time measures. His results were similar to those found here. Matthews argued that the violation of the monotonicity assumption in terms of time measures was likely to be a function of the differential effects of the times the cows spent in activities other than eating. Because variations in pausing affect time allocation to a larger extent than response allocation, strict transitivity would be less likely to hold for time measures. A similar argument, based on differing response durations as a result of pausing, probably applies here.

In the present experiment, the type of response required on the two alternatives differed across conditions. For example, in Conditions 1 and 2, both key pecking and door pushing were required, whereas in Conditions 3 and 4, only key pecking was required. Thus, in the present case, the number of responses, the topography of the responses, and hence the force required to emit each response varied. In other words, the current manipulations differed in more than just the time dimension (i.e., they were multidimensional). In Sumpter et al.'s (1998) study, it was shown that, unlike variations in response number, variations in required response force affect response and time allocation similarly. There was also some evidence that force requirements and reinforcer-rate ratios act jointly to affect both response and time allocation. Given that the response requirements differed in more than one dimension, the findings here, which imply an underlying unitary scale, are encouraging.

Despite the multidimensionality of the variations, these animals' data suggest that the ranking of the ''value'' of different paths to obtain the same outcome is possible. They also suggest that certain sorts of predictions can be made with a degree of confidence. They do, however, suggest that if one wished to predict an actual preference value for a third pair of response requirements, then the perfect transitivity (multiplicative) prediction is the ''best'' for response measures but may be inaccurate. If one is prepared to accept prediction of only a range, then prediction based on strong transitivity (i.e., the smaller range with the higher lowest level) would be good for response measures but not time measures. A wider prediction based on moderate transitivity will be satisfied in nearly all cases in terms of both behavior measures.

By implication, the present results suggest that if I prefer driving to work twice as much as riding a bus and prefer riding a bus three times more than cycling, then a prediction that I will prefer driving at least twice as much as cycling will rarely fail. However, a prediction that I will prefer driving six times more than cycling will underestimate as often as it will overestimate my observed preference.

The finding that response requirements lie on a unitary scale of value also supports models such as *unit price* (Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988) that are used in the assessment of animals' demand for environmental events. Underlying the unit price model (which suggests that one key peck at 750 grams-force represents the same price as 75 key pecks at 10 grams-force, etc.) is the notion of a unitary scale. The present results support this notion.

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APPENDIX

The sums of the last 5 days' data from each condition are presented for each bird.

		FR schedule		Responses		Time		Obtained reinforcers		Completed FR schedules		
Hen	Condition	L	R	L	R	L	R	L	R	L	R	Time
61	1	1	3	2,349	306	9,650	2,223	49	48	2,349	102	12,000
61	2	15	1	1,755	293	8,173	3,068	42	38	117	293	12,000
61	3	1	1	423	720	5,100	6,672	40	38	423	720	12,000
61	4	1	15	2,933	2,385	7,692	3,857	74	69	2,933	159	11,678
62	1	1	3	1,251	714	5,106	5,880	74	74	1,251	238	11,192
62	2	15	1	1,460	511	5,220	6,513	56	55	97	511	12,000
62	3	1	1	1,283	1,296	5,016	4,765	75	75	1,283	1,296	10,076
62	4	1	15	1,207	2,310	6,634	5,123	64	65	1,207	154	11,918
63	1	1	3	3,332	1,167	5,351	4,738	75	75	3,332	389	10,317
63	2	15	1	3,691	904	6,664	4,746	74	73	246	904	11,636
63	3	1	1	5,191	2,837	5,063	3,498	75	75	5,191	2,837	8,830
63	4	1	15	3,425	5,310	4,295	5,188	75	75	3,425	354	9,702
64	1	1	3	5,825	489	9,549	2,347	67	62	5,825	163	12,000
64	2	15	1	4,650	925	7,207	3,554	75	75	310	925	10,958
64	3	1	1	3,444	3,484	4,192	4,313	75	75	3,444	3,484	8,719
64	4	1	15	3,618	5,370	4,646	4,657	75	75	3,618	358	9,486
65	1	1	3	2,976	232	8,713	2,844	59	54	2,976	76	11,657
65	2	15	1	3,347	302	8,014	3,705	67	63	223	302	12,000
65	3	1	1	3,368	2,320	4,909	3,566	75	75	3,368	2,320	8,727
65	4	1	15	3,812	4,095	6,618	3,867	75	74	3,812	273	10,635
66	1	1	3	2,854	1,293	4,878	4,996	76	74	2,854	431	10,082
66	2	15	1	3,165	1,170	4,684	6,223	74	74	211	1,170	11,106
66	3	1	1	3,255	2,220	4,510	3,245	75	75	3,255	2,220	8,097
66	4	1	15	4,191	3,765	5,167	3,870	76	74	4,191	251	9,235