JOURNAL OF APPLIED BEHAVIOR ANALYSIS 2009, **42,** 609–625 NUMBER 3 (FALL 2009)

CONSUMPTION AND RESPONSE OUTPUT AS A FUNCTION OF UNIT PRICE: MANIPULATION OF COST AND BENEFIT COMPONENTS

XERES DELMENDO, JOHN C. BORRERO, KENNETH L. BEAUCHAMP, AND MONICA T. FRANCISCO

UNIVERSITY OF THE PACIFIC

We conducted preference assessments with 4 typically developing children to identify potential reinforcers and assessed the reinforcing efficacy of those stimuli. Next, we tested two predictions of economic theory: that overall consumption (reinforcers obtained) would decrease as the unit price (response requirement per reinforcer) increased and that the cost and benefit components that defined unit price would not influence overall consumption considerably when unit price values were equal. We tested these predictions by arranging unit price such that the denominator was one (e.g., two responses produced one reinforcer) or two (e.g., four responses produced two reinforcers). Results showed that consumption decreased as unit price increased and that unit price values with different components produced similar consumption.

DESCRIPTORS: behavioral economics, costs and benefits, preference assessment, reinforcer demand, unit price

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Methods of assessing preferred stimuli that will increase appropriate engagement and reduce levels of problem behavior have constituted an important area of research in behavior analysis (Ivancic, 2000). Several methods of determining stimulus preference and subsequent reinforcer efficacy have been reported (e.g., Fisher et al., 1992; Pace, Ivancic, Edwards, Iwata, & Page, 1985; Roane, Vollmer, Ringdahl, & Marcus, 1998). In these studies, evaluations of reinforcer efficacy have generally been arranged under relatively low schedule requirements (e.g., fixed-ratio [FR] 1), involving relatively low-effort responses (e.g., touching the experimenter's hand) that may not approximate more effortful responses required in applied settings (e.g., Fisher & Mazur, 1997; Roscoe, Iwata, & Kahng, 1999).

The conditions under which responding is predicted to persist under increasing response requirements may be informed by methods used in behavioral economics. The primary dependent variable in behavioral economic research is consumption, or the number of reinforcers obtained (Hursh, 2000; Johnson & Bickel, 2006). A second dependent variable in behavioral economic research measures spending, as either local or overall response output. In a traditional economic system, money serves as the currency or means by which one obtains necessities (e.g., water) and luxury items (e.g., large flat-screen televisions). In behavioral economic research with nonhumans and contemporary behavior-analytic reinforcer assessment research, the currency is behavior, and the commodities available for purchase are generally foods or preferred activities. Consumption and spending may thus be characterized as components of a cost–benefit arrangement, in which the ratio of cost (response requirement) over

This experiment was completed in partial fulfillment of the requirement of the MA degree by the first author. We thank Lucas Bradley for his comments on an earlier version of this manuscript and Adam Brewer, Patrick Johnson, and Greg Madden for their conceptual contributions to the demand analyses. We also thank Stephany Crisolo, Noel Ross, and Sandeep Sran for their assistance with data collection and various other aspects of this project. Portions of this research were presented at the 25th meeting of the California Association for Behavior Analysis in Burlingame and the 33rd meeting of the Association for Behavior Analysis in San Diego. Xeres Delmendo is now with Nyansa Learning Corporation, Santa Ana, California. Monica Francisco is now at the University of Kansas.

Address correspondence to John C. Borrero, who is now at the University of Maryland, Baltimore County, Department of Psychology, 1000 Hilltop Circle, Baltimore, Maryland 21250 (e-mail: jborrero@umbc.edu).

doi: 10.1901/jaba.2009.42-609

benefit (reinforcer magnitude) defines a simple formulation of unit price, which is represented by the equation

$$P = \frac{\mathrm{FR}}{A}, \qquad (1)$$

where price (P) is determined by, in this example, the FR requirement divided by the amount (A) of the reinforcer or its magnitude. Unit price may be altered by manipulating reinforcer magnitude or response requirements separately or in combination (Foster & Hackenberg, 2004). Thus, if completion of an FR 2 requirement is followed by one reinforcer, this is equivalent in price to completion of an FR 4 requirement that is followed by two reinforcers.

Behavioral economic research characterizes performance in terms of the exchange of responses and reinforcers. For example, if "spending" eight lever presses (response) produces one food pellet (reinforcement), a unit price analysis predicts that eight lever presses that produce one food pellet would be functionally equal to 16 lever presses that produce two food pellets. Thus, if both the response requirement and the reinforcer amount increase by the same constant, economic theory suggests that consumption will not be affected because the unit price of the reinforcer will be constant.

Given a range of unit price values, reinforcer demand can be empirically assessed. Demand refers to the amount of the commodity consumed relative to the price for each commodity (Hursh, 1980). The effects of changes in price (on consumption) are predicted to follow the law of demand, which states that, all else being equal, consumption of a commodity (reinforcer) decreases as its price increases (Freed & Green, 1991). Demand elasticity is the extent to which consumption of a commodity is influenced by alterations in price for that commodity (Green & Freed, 1993), and two types of demand are commonly discussed in the literature. *Inelastic demand* describes a less than proportional change in consumption as a function of changes in price, which yields a demand function with a slope between 0 and −1. If a 1% change in price produces a less than 1% change in consumption, demand is characterized as inelastic. *Elastic demand* describes a greater than proportional change in consumption as a function of changes in price, which yields a demand function with a slope more negative than −1 (Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988). If a 1% change in price produces a greater than 1% change in consumption, demand is characterized as elastic. In other words, a commodity for which demand is inelastic is one whose consumption is not greatly affected by changes in price (e.g., consumption may decrease as price increases, but decreases are less than proportional). By contrast, a commodity with elastic demand is one whose consumption is more affected by changes in price (e.g., consumption decreases in a greater than proportional fashion as price increases). For example, if the price of kiwis increased from $1.00 per kilgram to $2.00 per kilogram, this would represent a 50% increase in price. To characterize demand for kiwis as elastic, consumption would necessarily decrease by more than 50%. However, if consumption of kiwis decreased by only 10%, given a change in price from $1.00 per kilogram to $2.00 per kilogram, then consumption for kiwis would be characterized as inelastic.

Changes in the slope of the demand function (obtained by plotting reinforcer consumption against unit price) can be used to assess the relative reinforcing efficacy of stimuli. Given increases in price, stimuli that produce slopes more shallow than −1 are more valuable than those with slopes steeper than −1 (Allison, 1983). When plotted on double logarithmic coordinates, the function relating consumption and increasing unit price is positively decelerating, and the function relating response output to increases in unit price is typically an inverted U-shaped function (Bickel, Marsch, & Carroll, 2000).

Several recent studies have evaluated reinforcer efficacy under progressive-ratio schedules, in which response requirements increase within (e.g., Francisco, Borrero, & Sy, 2008; Glover, Roane, Kadey, & Grow, 2008; Roane, Call, & Falcomata, 2005; Roane, Lerman, & Vorndran, 2001) and across (e.g., DeLeon, Iwata, Goh, & Worsdell, 1997; Johnson & Bickel, 2006; Tustin, 2000) sessions. Results of these studies have been consistent with the law of demand in that decreases in consumption were generally associated with increases in response requirement.

Although not framed as such, the work of DeLeon et al. (1997) may also be assessed in terms of reinforcer demand. DeLeon et al. evaluated consumption of two concurrently available edible reinforcers (e.g., a cookie and a cracker) under progressively increasing schedule requirements. Responding for the two reinforcers was similar under low response requirements, but a preference emerged for one reinforcer (cookie) under increasing response requirements. These data illustrate that the value of one reinforcer (cookie) varied depending on the other concurrently available reinforcer. Results reported by DeLeon et al. raise important issues that should be evaluated. First, performance under a single schedule may not correspond to performance under concurrent schedules (e.g., Francisco et al., 2008; Roscoe et al., 1999). That is, consumption of one reinforcer might differ, depending on the presence or absence of alternative reinforcers. Second, in terms of behavioral programming, predicted performance should be similar when unit price remains the same across changes in the cost–benefit components. In other words, if maximal performance (as evidenced by the largest value of the inelastic portion of a demand function) occurs when *x* responses produce one reinforcer, similar performance should occur when 2*x* responses produce two reinforcers (i.e., unit price is unchanged). From a practical standpoint, such a finding might have an impact in classroom or institutional settings. For example, assume that a student's academic performance has been shown to persist when one reinforcer is delivered for every 10 responses. Assume further that a teacher's attention is diverted from the student for a period of time such that delivery of the reinforcer following Response 10 is omitted. Presumably, performance should be maintained at similar levels if two reinforcers were arranged for completion of 20 responses, and thus, a potentially detrimental instance of integrity failure (Peterson, Homer, & Wonderlich, 1982) might be avoided by a modest manipulation of reinforcer amount, thereby keeping unit price constant.

In addition to offsetting potential treatment integrity problems, evaluations of reinforcer demand may suggest the maximum schedule requirement under which stimuli maintain high value (i.e., $P_{\max}$ [the price at which peak responding is reached], and corresponding values along the inelastic portion of the demand function). In other words, in practice, clinicians attempt to identify the largest amount of work that can be maintained with the smallest reinforcer amount. If a client will complete 20 academic tasks for one reinforcer, it would be ill advised to arrange one reinforcer contingent on 10 academic responses. Similarly, it would be ill advised to arrange one reinforcer contingent on 50 academic responses. By setting a price that exceeds $P_{\max}$, spending (or work) will decrease. By setting a price that approaches $P_{\max}$, the value of the reinforcer is maintained, and the maximum amount of work is produced.

Evaluations of demand elasticity across various price arrangements may be useful in determining the conditions under which highly preferred stimuli, identified via preference assessment, will support clinically acceptable levels of responding under increasing response requirements. For example, more valuable stimuli (i.e., those that produce relatively shallow slopes) may be made contingent on more effortful behavior, and relatively less valuable stimuli (i.e., those that produce relatively steeper slopes) might be arranged contingent on less effortful behavior. By incorporating greater variety in the programmed consequences for behavior, satiation, at least with respect to a particular stimulus, may be minimized. Although such findings would be of importance to applied researchers, a preliminary assessment of reinforcer demand, with unit price held constant, is a prerequisite to more complex analyses like those involving qualitatively different stimuli.

Previous operant research with humans (e.g., Bickel & Madden, 1999; Madden, Bickel, & Jacobs, 2000) suggests that consumption will be similar under equal unit price values, regardless of the cost–benefit components. However, such findings have yet to be demonstrated in the context of reinforcer assessment research involving academic task completion. Thus, the purpose of the current investigation was to determine whether similar results would be obtained in the context of repeated reinforcer assessments in which unit price was held constant while cost–benefit components were varied. If consumption and response output are largely uninfluenced by cost–benefit components, behavioral programming may be enhanced. In other words, the unit price itself (e.g., six) may be more relevant in determining reinforcer demand than the methods used to arrange a unit price of six (e.g., 12 responses for two reinforcers or 36 responses for six reinforcers; Roane, Falcomata, & Fisher, 2007).

METHOD

Participants and Settings

Four typically developing children participated, and parental consent, as well as child assent, was obtained prior to data collection. Elijah was 4 years old, attended preschool 4 days per week, and attended an afterschool care program. Anna and Elizabeth were both 3 years old and attended preschool 5 days per week. Keelan was 6 years old and attended first grade. Sessions for Elijah, Anna, and Elizabeth were conducted in a small room at their respective schools. The room contained a desk, a table, several chairs, and various teaching materials. Sessions for Keelan were conducted in the dining room of his home. The room contained a dining table, four chairs, and a shelf. Sessions were conducted one to three times per day, 4 to 5 days per week for each child. As part of the intake and consent procedure, parents indicated which foods were prohibited due to food allergies or parental preference. Prior to the initiation of data collection, the university institutional review board approved this study.

Response Measurement and Interobserver Agreement

During the preference assessment, data were collected on *consumption* (defined as an edible item passing the plane of the participant's lips). During the reinforcer assessment and reinforcer demand evaluations, target academic responses were selected according to the participant's academic level, based on consultation with the participant's teachers. The target response was tracing (letters and numbers) for Elijah, sorting beads by color for Anna, completion of writing worksheets for Keelan, and color matching for Elizabeth. For the tracing task, a response was recorded when the participant completely traced either one letter or one number. For the bead-sorting task, a response was recorded when the participant placed one like-colored bead among an array of beads arranged in a sorting receptacle. For the color-matching task, the participant was required to place an object of one color in a receptacle containing like-colored stimuli.

Trained observers were seated unobtrusively in the room and collected data using paper and pencil (preference assessment) or handheld personal digital assistants. Interobserver agreement was assessed by having a second observer simultaneously but independently record consumption and academic responses. Agreement was calculated using the method of partial agreement within intervals (Vollmer, Borrero, Wright, Van Camp, & Lalli, 2001). Data were assessed by dividing the entire session into consecutive 10-s intervals, and the smaller number in each 10-s interval was divided by the larger number. Interobserver agreement data during the free-operant preference assessment were collected during 50%, 33%, 67%, and 67% of sessions for Elijah, Anna, Keelan, and Elizabeth, respectively (multiple preference assessments were conducted for each participant, described below). Agreement for consumption during the preference assessment were 90% for Elijah, 100% for Anna, 72% for Keelan, and 96% for Elizabeth. During the reinforcer assessment, agreement data were collected during 41%, 30%, 29%, and 76% of sessions for Elijah, Anna, Keelan, and Elizabeth, respectively. These values were then averaged for the entire session. Agreement values for academic responding during the reinforcer assessment were 92% for Elijah (range, 88% to 93%), 100% for Anna, 98% for Keelan (range, 95% to 100%), and 95% for Elizabeth (range, 86% to 100%). During the reinforcer demand evaluation, agreement data were collected during 38%, 36%, 44%, and 37% of sessions for Elijah, Anna, Keelan, and Elizabeth, respectively, and were 88% for Elijah (range, 74% to 100%), 95% for Anna (range, 81% to 100%), 89% for Keelan (range, 60% to 100%) and 97% for Elizabeth (range, 86% to 100%).

Preference Assessment: Procedure

The purpose of the preference assessment was to identify one food item that would function as a potential reinforcer for the subsequent analyses. Each participant's behavior was exposed to two (Elijah) or three (Anna, Elizabeth, and Keelan) preference assessments using the procedures described by Roane et al. (1998). During the preference assessment, only food items were evaluated. A total of 10 foods (in bite-size portions) were arranged in a circle on a table, and participants could consume the food freely. Foods were replenished such that no food was ever unavailable. Consumption was recorded using a 10-s partial-interval recording system. It was possible for participants to consume multiple foods during a given 10-s interval. Preference was determined by recording the percentage of 10-s intervals during which consumption of each food occurred. In other words, the number of 10-s intervals with consumption of each food was divided by the total number of intervals in the session, and multiplied by 100%. Results of each preference assessment were averaged, and the food item consumed during the greatest mean percentage of intervals was subsequently evaluated via reinforcer assessment.

Reinforcer Assessment: Procedure and Design

The purpose of the reinforcer assessment was to determine whether items consumed most during the preference assessment would function as reinforcers when delivered contingent on academic responding. The academic response for each child was defined previously and served as the dependent variable during the reinforcer assessment. During baseline (A), the therapist presented the participant with the instructional materials (e.g., a tracing worksheet) and permitted the participant to engage in the activity. However, the therapist did not deliver reinforcers for academic responding, and edible items were not present or in view. During the reinforcement condition (B), the therapist presented the participant with the same task used in baseline; however, the therapist delivered reinforcers for academic responding on an FR 1 schedule. Edible items were both present and in view during this condition. Reinforcer efficacy was evaluated using an A-B-A design, and a minimum of three sessions per condition were conducted. After demonstration of a reinforcement effect, participants proceeded to the reinforcer demand evaluation.

Reinforcer Demand Evaluation: Procedure

The purpose of the reinforcer demand evaluation was to assess consumption and

Table 1
Sequence of Conditions and Exposure

			Series 1			Series 2		
Participant	Edible item	Unit price	Sessions	Fixed ratio	Edible item	Sessions	Fixed ratio	Edible item
Elijah	Candy	2	7	2	1	7	4	2
		4	5	4	1	5	8	2
		6	5	6	1	5	12	2
		8	6	8	1	5	16	2
		15	5	15	1	5	30	2
						5	45	1
Anna	Chips	2	5	2	1	7	4	2
		4	6	4	1	8	8	2
		6	5	6	1	5	12	2
		8	5	8	1	5	16	2
		16	5	16	1	6	32	2
Keelan	Chips	2	5	2	1	5	4	2
		4	7	4	1	7	8	2
		6	9	6	1	9	12	2
		8	5	8	1	5	16	2
		15	5	15	1	5	30	2
Elizabeth	Cookies	2	5	2	1	5	4	2
		4	6	4	1	5	8	2
		6	5	6	1	5	12	2
		8	5	8	1	5	16	2

performance given increasing response requirements and to assess consumption and performance under equal unit price values composed of different cost–benefit components. Each participant completed two reinforcer demand evaluations (hereafter referred to as "series"). In Series 1, completion of the predetermined FR schedule requirement resulted in one reinforcer. For example, given an FR 15 response requirement, completion of 15 academic responses produced one bite of the participant's most preferred food. In Series 2, completion of the predetermined FR schedule requirement resulted in two reinforcers. Thus, to ensure an equal unit price (in this example), an FR 30 schedule was arranged, which resulted in delivery of two reinforcers. The sequence of exposures, specific unit price values, cost and benefit components, response requirements, and reinforcers are summarized in Table 1. Prior to Series 1, all participants had just completed the baseline condition of the prior reinforcer assessment phase, and thus we concluded that in the absence of programmed contingencies, participants would not emit the target academic response or would do so at low levels.

Prior to the first reinforcer demand session, the participant was told that he or she could earn a bite of their favorite food for completing a specific number of responses, and that he or she could consume the food. A minimum of five sessions was conducted for each unit price in each series, and sessions were terminated when one of the following criteria was met: (a) 3 min elapsed without a response, or (b) the participant emitted the vocal response, "I'm done." The latter termination criterion was included to reduce the likelihood of disruptive behavior that might have occurred by requiring participants to stay seated for 3 min.

RESULTS

Figure 1 depicts the mean results of the preference assessments for all participants. Results suggested that candies, chips, chips, and cookies might serve as potential reinforcers for Elijah, Anna, Keelan, and Elizabeth, respectively.

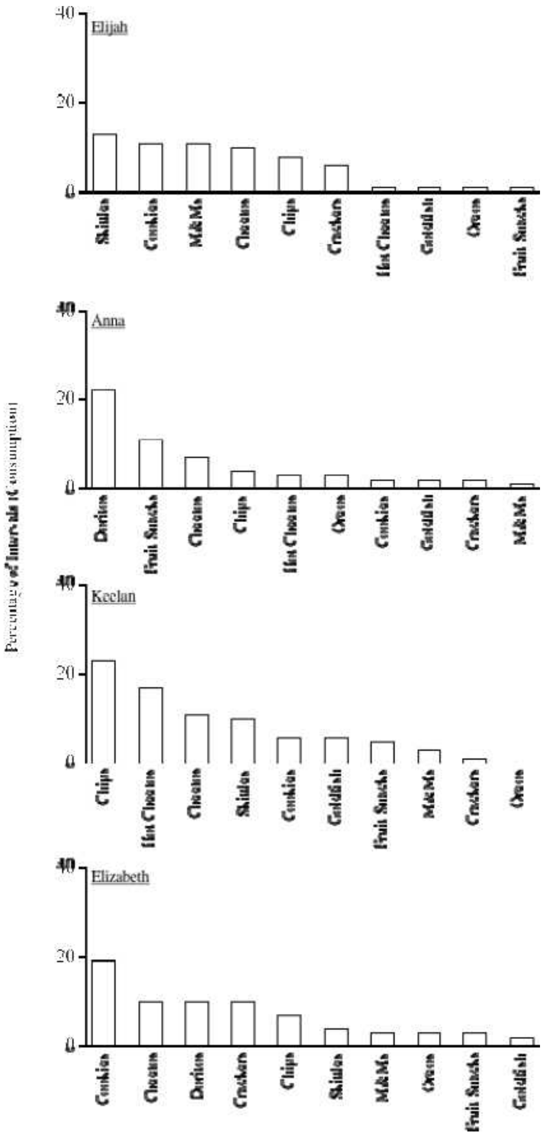

Figure 1. Preference assessment results for all participants. Note that the scale of the *y* axis is set to a maximum of 40.

Figure 2 depicts the results of the reinforcer assessment for all participants. In the initial baseline condition, in which edible items were not available contingent on academic responding, mean response rates were generally low for all participants. When reinforcers were delivered on an FR 1 schedule, mean response rates increased relative to baseline levels for all participants, and subsequently decreased when contingent food was withdrawn. Based on these results, we concluded that these edible items served as reinforcers for each participant's academic responding.

Figure 3 depicts results of the reinforcer demand evaluations for all participants. Data from the last four sessions are reported because this is the method of data aggregation used in the majority of behavioral economic research with nonhumans and also eliminates data that might be anomalous due to transitions from one unit price value to the next.

The objective of Series 1 (Figure 3) was to determine the level of academic responding, and by extension, the number of reinforcers obtained, when the price of the reinforcer was systematically increased. In brief, as the number of academic responses required was increased, the number of reinforcers obtained decreased, consistent with the law of demand. More specifically, during Series 1 for Elijah (top left) and Anna (second left), demand was inelastic (there was a less than proportional change in consumption as a function of the change in price) when price was increased from Unit Price 2 to Unit Price 4. Specifically, the slope of the function from Unit Price 2 to Unit Price 4 was -0.97 for Elijah and -0.15 for Anna. Recall that slopes between 0 and -1 define inelastic demand, which means that although academic responding did decrease for Elijah, the proportional decrease in reinforcers obtained was less than the proportional increase in price. Or, the value of the edible item was maintained despite requiring more academic work to produce it. Subsequent increases in price during Series 1 (e.g., from Unit Price 4 to Unit Price 6) resulted in largely elastic demand (greater than proportional change in consumption as a function of changes in price), which means that at these higher prices, proportional decreases in reinforcers obtained were greater than the proportional increases in price, with the exception of the transition between Unit Price 6 and Unit Price 8 for Anna (slope = 0.28). In

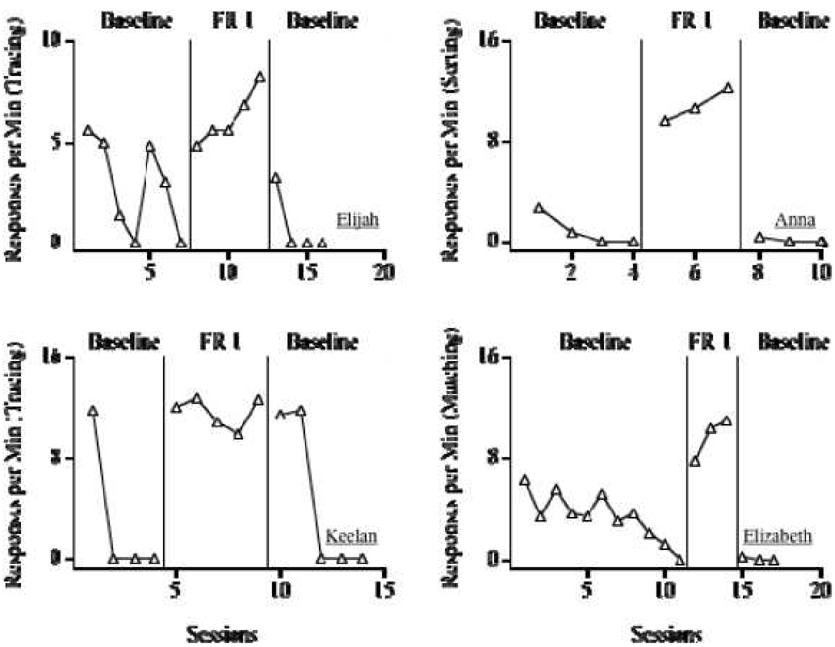

Figure 2. Results of the reinforcer assessment for all participants. See text for a description of the contingencies in place during baseline and FR 1.

other words, as the price of the edible item increased, the number of academic responses required was too great and resulted in less responding than would have been predicted given the proportional increase in price. By contrast, slopes for Keelan (third left) and Elizabeth (bottom left) were indicative of elastic demand during transitions from even the smallest unit price values (Unit Price 2 to Unit Price 4) during Series 1 (slope = −1.70 for Keelan and −2.82 for Elizabeth) suggesting that even these very modest increases in price were too much to maintain academic responding at sufficiently high levels. In addition, response output increased from Unit Price 2 to Unit Price 4 for Elijah and Anna (slopes = 0.14, and 0.86, respectively). These data illustrate that even though the number of academic tasks completed might increase, the total amount of reinforcers obtained can decrease (because more work is required to earn reinforcers when the price of a reinforcer increases). From a practical standpoint, this means that Elijah and Anna completed more work when the price increased but earned less for every instance of academic responding. Results for Keelan and Elizabeth illustrate the opposite change in response output. Response output decreased slightly for Keelan and Elizabeth (slopes = −0.72, and −0.83, respectively), which means that they responded less when the price of the reinforcer was increased, but the decrease was within the expected (proportional) range. This underscores the fact that increases in academic responding are only contextually related to evaluations of demand (i.e., a child may emit more absolute responding under increasing price requirements, but this does not in and of itself suggest greater stimulus value). If the number of reinforcers obtained under these higher price requirements decreases in a greater than proportional fashion, the stimulus has still lost some of its value.

The objective of Series 2 (Figure 3) was to determine the extent to which changes in consumption would be observed when unit price was held constant and the cost and benefit components were varied. In other words, for each unit price assessed, the objective was to determine the extent to which reinforcers obtained and task completed would be similar at the same unit price values. For 3 of 4 participants (Elijah, Keelan, and Elizabeth), there was considerable similarity in terms of reinforcers obtained across Series 1 and Series 2. In other words, from the perspective of 3 participants, a situation in which, for example, two academic responses were required for one reinforcer was viewed as similar to a situation in which four academic responses were required for two reinforcers. Data for Anna, during the transition from Unit Price 2 to Unit Price 4, were the exception (although the overall pattern remained unchanged). A second objective of Series 2 was to determine the point at which demand transitioned from inelastic to elastic; that is, when the change in the number of reinforcers obtained moved from decreases that would be expected proportionally to decreases that were larger proportionally than expected. For all participants, these transition values (i.e., specific price increases such as Unit Price 4 to Unit Price 6 for Elijah in Series 1 and Series 2) were identical. This can be illustrated with Anna's data. For the other 3 participants, the data paths are either fairly close to one another or on top of one another, at the same unit price. For Anna, reinforcers obtained for Unit Price 2 in Series 1 are greater than the number of reinforcers obtained in Series 2. The same is true for Unit Price 4 (note that open circles are consistently higher than closed triangles for Anna, across all unit price values). Despite the differences in the number of reinforcers obtained from Series 1 to Series 2 across these two price values, the point at which her academic responding was proportionally greater than the increase in price was still the same from Series 1 to Series 2. In other words, when either six responses were required for one reinforcer (Series 1) or 12 responses were required for two reinforcers, this is the price (Unit Price 6) at which decreases in the number of reinforcers obtained (and by extension, tasks completed) were proportionally greater than the change in price from Unit Price 4 to Unit Price 6. Thus, despite the differences in Anna's overall consumption (Figure 3), demand was characterized as elastic in both Series 1 and Series 2, following the transition from Unit Price 4 to Unit Price 6. Reinforcer demand in Series 2 changed somewhat for Elijah compared to Series 1 (Figure 3). Because mean reinforcers obtained in Series 2 at Unit Price 15 exceeded consumption from Series 1 under Unit Price 15 (the largest unit price value assessed in Series 1), an increase in unit price was introduced. Specifically, it appeared that the value of the commodity changed from Series 1 to Series 2. Thus, Unit Price 45 was introduced. The transition from Unit Price 15 to Unit Price 45 produced a decrease in reinforcers obtained that was considered proportional to the rather large increase in price and resulted in a transition slope of −0.89 (or degree of change).

Figure 4 depicts data for the last four sessions conducted at each unit price (instead of the means of those sessions depicted in Figure 3). For all participants, reinforcers obtained (left) were fitted using the logarithmic version of the equation proposed by Hursh et al. (1988):

$$\ln C = \ln L + b(\ln P) - aP, \qquad (2)$$

to evaluate the functional relation between total reinforcers consumed per session (C) and unit price (P). L is an estimate of reinforcers obtained that would occur at Unit Price 1, and b and a are related to the initial slope and acceleration of the demand function, respectively. Data on academic responding (right) were fitted to the same equation, except that $b + 1$ was substituted for b (Hursh, Raslear, Bauman, & Black, 1989). When the number of reinforcers obtained was zero (i.e., Anna at Unit Price 16 during Series 2, Keelan at Unit Price 15 during Series 2, and Elizabeth at Unit Price 8 during Series 2), a value of 0.1 was plotted so that data for all four sessions would be visible for inspection.

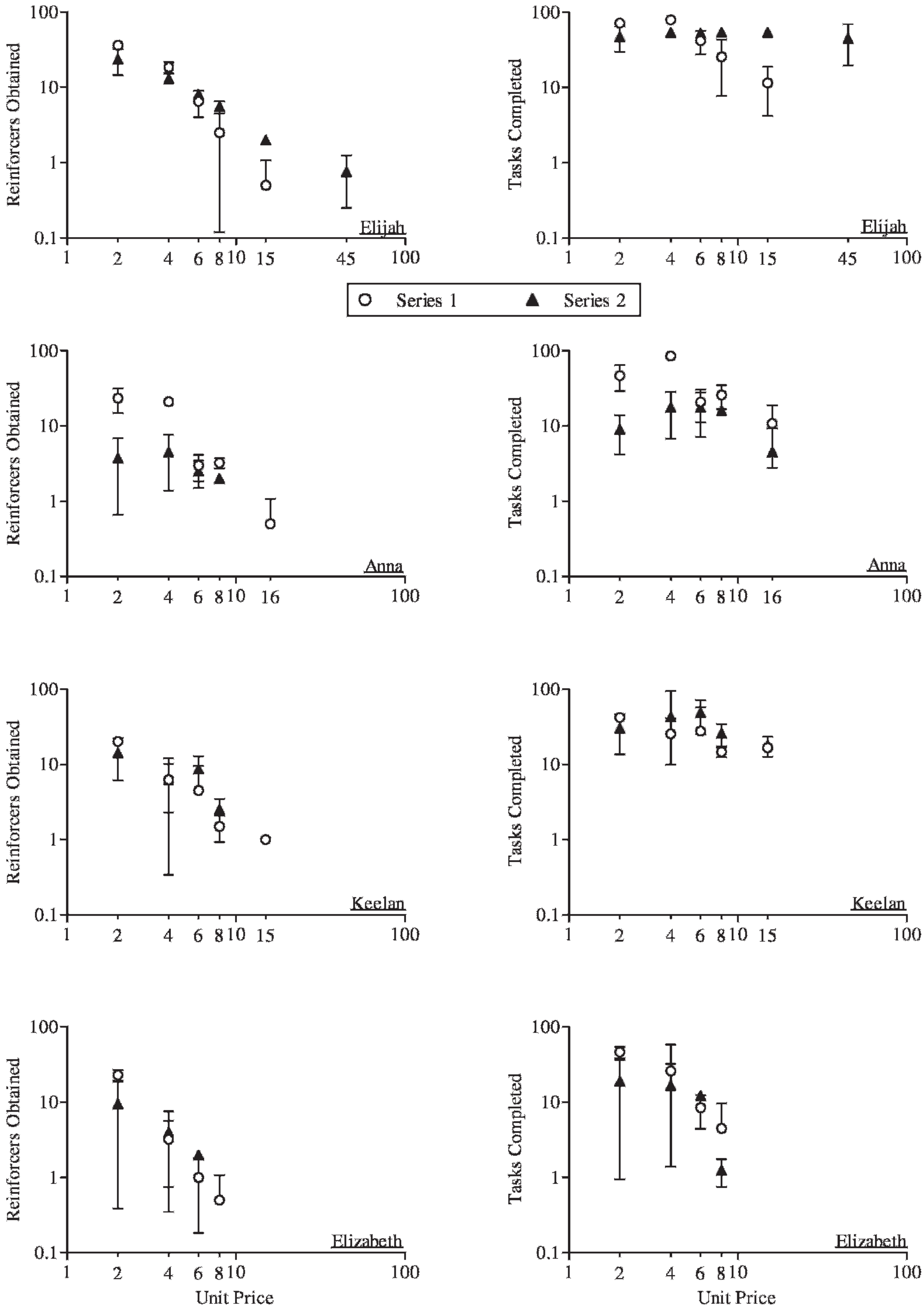

Figure 3. Results of the demand analysis for all participants. Each participant's data occupies one row. Each data point represents mean number of reinforcers earned (left column) or mean number of tasks completed (right column), across the last four sessions of the condition, for all participants (session-by-session data are available from the second author). Data are expressed on double logarithmic axes. Open circles depict data from Series 1, and filled triangles depict

Figure 4 illustrates the variability in the number of reinforcers obtained and academic task completion within each unit price and between Series 1 and Series 2. For Elijah (top), reinforcers obtained appeared to be more variable overall in Series 1, when one reinforcer was delivered after completion of the response requirement, relative to consumption in Series 2, when two reinforcers were delivered for completing the requirement. Similar patterns in variability were observed for task completion for Elijah (top row, right). For Anna (second row), variability in the number of reinforcers obtained (left) and academic task completion (right) in Series 1 and 2 were relatively similar. However, unlike the patterns observed with Elijah, Anna's reinforcers obtained and academic task completion appeared to be more variable within each unit price during Series 2 than in Series 1. Data for Keelan (third row) and Elizabeth (bottom row) do not appear to show substantial variability in number of reinforcers obtained or academic task completion between Series 1 and 2; the spread of data points is fairly equal across unit prices and series.

To further evaluate responding across Series 1 and 2, differences in the number of reinforcers obtained were derived by taking the largest difference in mean consumption (19.5 for Anna), rounding that value to the nearest whole number (20), and dividing that value in half twice to obtain comparison values. Thus, these values represent differences of 25% and 50% of reinforcers obtained when standardized using the largest difference obtained for all participants. It should be noted that because all participants were not exposed to all of the exact same unit price values, the areas of greatest similarity in number of reinforcers obtained should also be assessed across participants for like values (unit price values of 2, 4, 6, and 8). The lack of uniformity in unit price values across participants was the result of miscommunication between experimenters.

For 19 comparative opportunities (e.g., five for Elijah, five for Anna), differences in the number of reinforcers obtained were less than 10 reinforcers in 15 of 19 comparisons (79%) and less than five in 13 of 19 comparisons (68%). For unit price values of 2 and 4, differences in the number of reinforcers obtained across participants exceeded 10 in four of eight comparisons (for Elijah at Unit Price 2, for Anna at Unit Price 2 and Unit Price 4, and for Elizabeth at Unit Price 2). On the other hand, at Unit Price 6 and Unit Price 8, differences in consumption exceeded 10. Like results reported by Madden et al. (2000), the number of reinforcers obtained was similar, but in the current experiment, was rarely the same (Keelan at Unit Price 4 in Series 1 and Series 2 was the exception).

DISCUSSION

After identifying potential reinforcers by way of preference assessment, preferred edible items were tested for reinforcer efficacy under a low schedule requirement (FR 1). Having demonstrated that these items reinforced academic task completion, reinforcer demand was assessed. The reinforcer demand evaluations were designed to mirror procedures used in traditional human operant research, the purpose of which

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data from Series 2. Bars represent standard deviations (*SD*); data points with *SD* values equal to zero do not have bars, and those with *SD* values less than 1 have bars that may not be visible. Also note that all data points with bars are plotted with both upper and lower bars, although this may not be visible due to the nature of logarithmic axes. Series 1 and Series 2 were differentiated only in terms of the FR requirement and the number of reinforcers delivered after completion of the nominal FR requirement (one in Series 1, two in Series 2). The exception was for Elijah at Unit Price 45 of Series 2, in which completion of 45 responses resulted in one reinforcer.

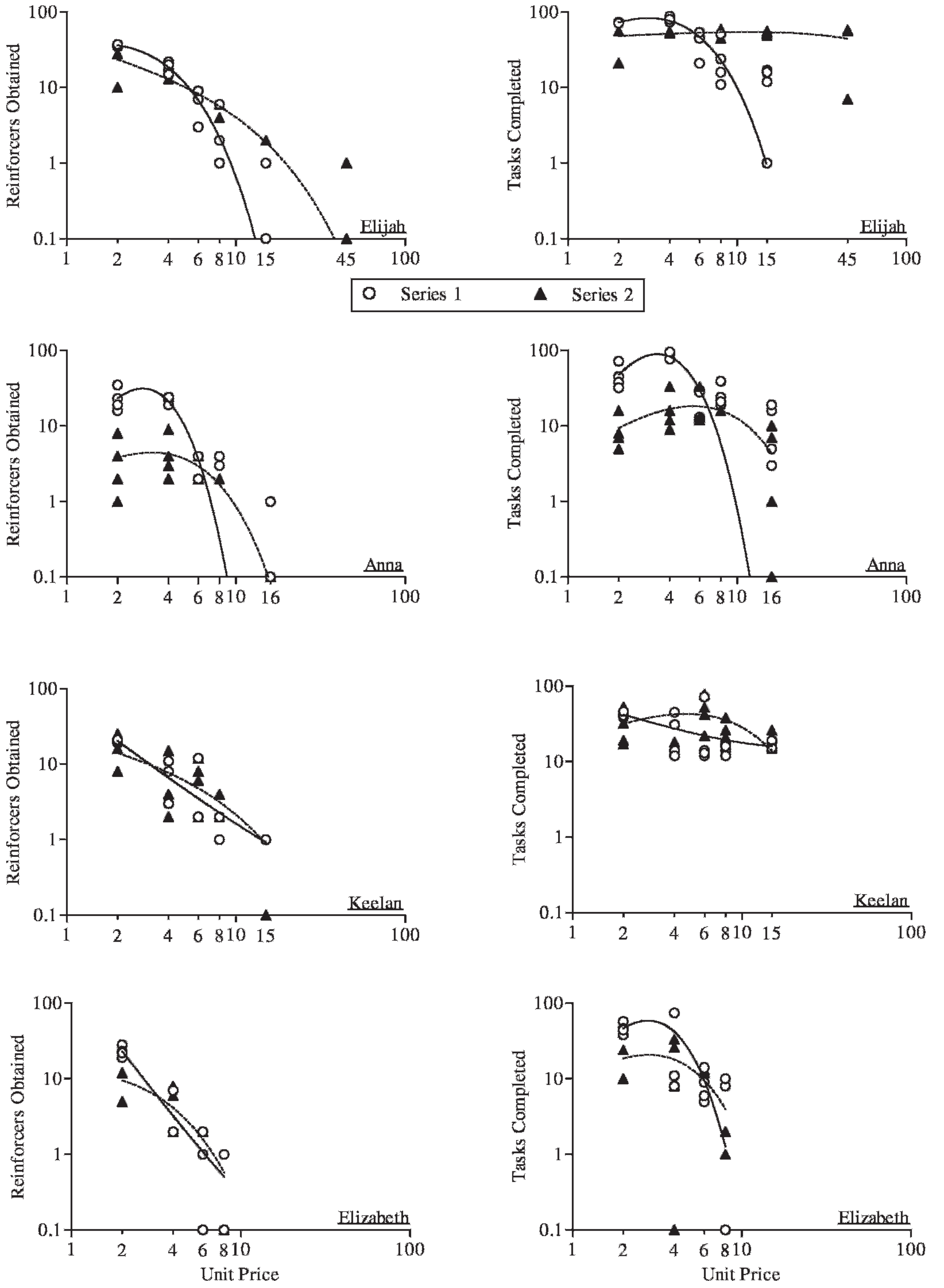

Figure 4. Results of the demand analysis fitted with the Hursh et al. (1988) equation for Elijah, Anna, Keelan, and Elizabeth. The last four sessions conducted for each unit price are depicted. Demand functions (reinforcers obtained as a function of unit price) appear in the left column, and work functions appear in the right column (tasks completed as a function of unit price). Data are expressed on double logarithmic axes. Open circles depict data from Series 1, and filled

was to ensure that results were mutually interpretable. Results of the reinforcer demand evaluations showed that as the price of the commodity increased, consumption decreased—a finding that is consistent with the law of demand and much of the previous applied research in behavioral economics (e.g., Roane et al., 2001; Tustin, 1994). Results of the reinforcer demand evaluation also showed that the number of reinforcers obtained was similar (although not identical) at some values under equal unit price values comprised of unequal cost and benefit components.

Results of the current investigation add to both the basic and applied studies on the utility of behavioral economic concepts in the experimental analysis of behavior by extending evaluations of cost and benefit components to the academic task completion of typically developing young children. Unlike prior descriptive research on the construct of unit price (Borrero, Francisco, Haberlin, Ross, & Sran, 2007) results of the current investigation suggest that even modest price increases (from Unit Price 2 to Unit Price 4) had a considerable impact on reinforcers obtained for 2 of 4 participants in Series 1. In application, this means that for Keelan and Elizabeth, requiring four responses for each reinforcer (rather than two) considerably reduced how many reinforcers were earned. Although this finding is similar to those reported in other behavioral economic research (e.g., Madden et al., 2000), it is suggestive of a procedural modification that may bring the behavior of participants in human operant research and those of nonhumans in basic research more closely in line with those of school-aged children completing academic tasks. To assess the entirety of both demand and work functions, smaller unit price values may be required. In the current study, although Unit Price 2 was assessed as the lowest price, starting with Unit Price 2 may have placed the beginning of the evaluation further along the curve (more to the right) than starting at a smaller value. In other words, we may have made the initial response requirement too difficult. To obtain the positively decelerating function that is so characteristic of consumption in human operant laboratories and the bitonic or inverted U-shaped function that is so characteristic of response output, unit price values may need to begin with values of one or less than one (e.g., one response produces three reinforcers, then one response produces two reinforcers). In short, evaluations of these smaller values may allow a more complete assessment of the reinforcer demand function. This would help to characterize the rapid decreases in academic responding that were observed, and provide clinicians with a better starting point for behavioral programming (i.e., inform how much responding can be supported by a specific magnitude of reinforcement). It may also be the case that the formal response unit (academic tasks in the present experiment and presumably arbitrary and less effortful responses in more traditional human operant research) may be responsible for any differences observed in number of reinforcers obtained. To evaluate this possibility, future research may be designed to replicate the procedures used in the present investigation during conditions in which the effort associated with the response unit is varied (e.g., academic tasks, button presses).

Madden et al. (2000) also assessed consumption in a concurrent arrangement, whereas a

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triangles depict data from Series 2. Nonlinear regression curves are depicted by dotted lines for Series 1 data and by solid lines for Series 2 data. Series 1 and 2 were differentiated only in terms of the FR requirement and the number of reinforcers delivered after completion of the nominal FR requirement (one in Series 1, two in Series 2). The exception was for Elijah at Unit Price 45 of Series 2, in which completion of 45 responses resulted in one reinforcer.

single arrangement was used to assess consumption in the present experiment. To the extent that one can infer what an individual prefers by assessing what and how much he or she consumes, children in the current study worked and earned more when fewer academic tasks were required. Thus, future research should assess whether such unit price manipulations affect responding differently (i.e., under concurrent- or single-schedule arrangements).

As suggested previously, results of the current experiment may be interpreted in terms of behavioral programming for academic and institutional settings. This suggestion will need to be applied with caution and evaluated further. Recall that the number of reinforcers obtained was similar at the midrange price values (e.g., Unit Price of 4); however, the most similar levels of reinforcers obtained were also associated with the elastic portion of the demand function. In application, the values selected as ideal for maintaining high and consistent levels of responding would be the range of values for which the curve is inelastic (i.e., when responding for the reinforcer persists). The present results from both Series 1 and Series 2 suggest that these values were Unit Price 2 or Unit Price 4, which are relatively rich schedule requirements that may be impractical to implement in applied settings. From this and related research, one conclusion that can be drawn is that, within limits, the cost and benefit components of unit price are of less importance than the unit price itself. To add support to this conclusion, future applied research might assess several different cost and benefit arrangements that hold price constant and approximate $P_{\max}$ or the price at which peak responding is reached. In other words, if peak responding is observed under a Unit Price 10, future research might be designed to assess several different cost and benefit components that result in a Unit Price 10 (e.g., 10 responses for one reinforcer, 20 responses for two reinforcers, 30 responses for three reinforcers). If in fact unit price is the essential component, the number of reinforcers obtained across all three of these examples should be similar. By conducting this work in applied settings we may also improve our understanding of the boundaries at which performance is similar (e.g., academic task completion of a 4-year-old may look one way when 10 responses produce one reinforcer but entirely different when 100 responses produce 10 reinforcers).

In the present experiment, participants' behavior was exposed to changes in price in an ascending sequence (e.g., unit price of 2, then 4, then 6 across both Series 1 and Series 2). The ascending sequence was selected to avoid masking any potential sequence effects that might have occurred. However, data for Elijah may be indicative of tolerance to increasing price requirements in that the sequence used in the current study is analogous to procedures used in the demand-fading literature to increase compliance with academic or self-care tasks (e.g., Ringdahl et al., 2002). Future investigations might involve random or quasi-random exposures to price. For example, rather than exposing behavior to an ascending sequence, perhaps these demand evaluations could begin with a midrange value (e.g., Unit Price 6), followed by either relatively smaller or relatively larger values. However, prior research has shown that similar demand functions are produced by ascending and random presentations of FR schedules (Giordano, Bickel, Shahan, & Badger, 2001; Raslear, Bauman, Hursh, Shurtleff, & Simmons, 1988). Elijah's results were somewhat unusual in this respect, and possible explanations may be warranted. There may be at least three possibilities for his persistent responding in Series 2 (Figure 3, top right). The first was noted above. A second possibility is that the reinforcing efficacy of the academic task (tracing) may have changed during the course of the experiment. That is, responding may have persisted due to automatic reinforcement (Vaughn & Michael, 1982) that was independent of the programmed contingencies arranged by the experimenters. A third possibility relates to the concept of stimulus value. As existing research has shown, reinforcer preference may change over time (Zhou, Iwata, Goff, & Shore, 2001; Zhou, Iwata, & Shore, 2002). Although the possible explanations listed above are not mutually exclusive, it is conceivable that like stimulus preference, stimulus value also may change over time. In this case, the reinforcing efficacy of candy may have changed as a function of variables completely unrelated and uncontrolled in the present experiment (e.g., perhaps access to these or similar stimuli was permitted outside the sessions in Series 1, but was restricted in Series 2). Although we attempted to restrict access to these items beyond experimental sessions (parents and teachers were asked to restrict access to the specific items assessed in this study), this variable could not be controlled experimentally.

From a practical perspective, the analyses described in the current study may not be amenable to applied contexts; however, the basic premise could be potentially useful in applied settings. In an attempt to make reinforcer demand analyses more practical for direct clinical application, future research on the assessment of reinforcer value might involve less frequent probes at differing unit price values comprised of different cost and benefit components (e.g., Madden, Dake, Mauel, & Rowe, 2005). In other words, reinforcer assessments could be designed such that the reinforcing efficacy of stimuli may be assessed over a range of unit prices (and cost and benefit combinations), and outcomes could be evaluated based on demand elasticity. This information could be used to differentially program contingencies for a child's academic task completion based on the subjective effort associated with one of multiple response options. If analyses indicate a relatively inelastic reinforcer demand, that particular reinforcer may be used to support more effortful academic responses (Glover et al., 2008). Conversely, reinforcers that produce a relatively more elastic demand curve may be more suitable for maintaining less effortful responses when delivered contingently. Further, future applied research also may involve comparisons of procedures that have been assessed to determine relative reinforcer efficacy. Madden, Smethells, Ewan, and Hursh (2007) have noted that measures of assessing reinforcer efficacy have generally involved progressive-ratio schedule breakpoints, peak response rate, and response allocation under concurrent-schedules arrangements. Unfortunately, the basic literature suggests that no single one of these measures alone should be used to assess reinforcer efficacy (Bickel et al., 2000). Thus, similar comparative analyses conducted by applied researchers in applied contexts will at the very least provide additional information for consideration.

Applied researchers may benefit considerably from current behavioral economic research. The implications for behavioral economic procedures and methods of characterizing spending and consumption represent a ripe area for future applied research. We submit that the current study represents one that is not appropriately characterized as either a strictly basic or strictly applied study. Rather, the current study might be better positioned at some midpoint along the basic–applied continuum, representing a type of translational research (Lerman, 2003). Thus, although the implications of the construct assessed in the current study remain conceptually sound with experimental corroboration from the laboratory, they must be assessed at a more practical level to have an impact in applied contexts.

REFERENCES

Allison, J. W. (1983). *Behavioral economics*. New York: Praeger.

Bickel, W. K., & Madden, G. J. (1999). A comparison of measures of relative reinforcing efficacy and behavioral economics: Cigarettes and money in smokers. *Behavioural Pharmacology*, *10*, 627–737.

Bickel, W. K., Marsch, L. A., & Carroll, M. E. (2000). Deconstructing relative reinforcing efficacy and situating the measures of pharmacological reinforcement with behavioral economics: A theoretical proposal. *Psychopharmacology*, *153*, 44–56.

Borrero, J. C., Francisco, M. T., Haberlin, A. H., Ross, N. A., & Sran, S. K. (2007). A unit price evaluation of severe problem behavior. *Journal of Applied Behavior Analysis*, *40*, 463–474.

DeLeon, I. G., Iwata, B. A., Goh, H., & Worsdell, A. S. (1997). Emergence of reinforcer preference as a function of schedule requirements and stimulus similarity. *Journal of Applied Behavior Analysis*, *30*, 439–449.

Fisher, W. W., & Mazur, J. E. (1997). Basic and applied research on choice responding. *Journal of Applied Behavior Analysis*, *30*, 387–410.

Fisher, W., Piazza, C. C., Bowman, L. G., Hagopian, L. P., Owens, J. C., & Slevin, I. (1992). A comparison of two approaches for identifying reinforcers for persons with severe and profound disabilities. *Journal of Applied Behavior Analysis*, *25*, 491–498.

Foster, T. A., & Hackenberg, T. D. (2004). Unit price and choice in a token- reinforcement context. *Journal of the Experimental Analysis of Behavior*, *81*, 5–25.

Francisco, M. T., Borrero, J. C., & Sy, J. R. (2008). Evaluation of relative and absolute reinforcer value using progressive-ratio schedules. *Journal of Applied Behavior Analysis*, *41*, 189–202.

Freed, D. B., & Green, L. (1991). The economics of substitutability in psychological studies of choice. *Polish Psychological Bulletin*, *23*, 285–308.

Giordano, L., Bickel, W. K., Shahan, T. A., & Badger, G. J. (2001). Behavioral economics of human drug self-administration: Progressive ratio vs. random sequences of response requirements. *Behavioural Pharmacology*, *12*, 343–347.

Glover, A. C., Roane, H. S., Kadey, H. J., & Grow, L. L. (2008). Preference for reinforcers under progressive- and fixed-ratio schedules: A comparison of single- and concurrent-operant arrangements. *Journal of Applied Behavior Analysis*, *41*, 163–167.

Green, L., & Freed, D. E. (1993). The substitutability of reinforcers. *Journal of the Experimental Analysis of Behavior*, *60*, 141–158.

Hursh, S. R. (1980). Economic concepts for the analysis of behavior. *Journal of the Experimental Analysis of Behavior*, *34*, 219–238.

Hursh, S. R. (2000). Behavioral economic concepts and methods for studying health behavior. In W. K. Bickel & R. Vuchinich (Eds.), *Reframing health behavior change with behavioral economics* (pp. 27–60). Mahwah, NJ: Erlbaum.

Hursh, S. R., Raslear, T. G., Bauman, R., & Black, H. (1989). The quantitative analysis of economic behavior with laboratory animals. In K. G. Grunert & F. Ölander (Eds.), *Understanding economic behaviour* (pp. 393–407). Boston: Kluwer Academic.

Hursh, S. R., Raslear, T. G., Shurtleff, D., Bauman, R., & Simmons, L. (1988). A cost-benefit analysis of demand for food. *Journal of the Experimental Analysis of Behavior*, *50*, 419–440.

Ivancic, M. T. (2000). Stimulus preference and reinforcer assessment applications. In J. Austin & J. E. Carr (Eds.), *Handbook of applied behavior analysis* (pp. 19–38). Reno, NV: Context Press.

Johnson, M. W., & Bickel, W. K. (2006). Replacing relative reinforcing efficacy with behavioral economic demand curves. *Journal of the Experimental Analysis of Behavior*, *85*, 73–93.

Lerman, D. C. (2003). From the laboratory to community application: Translational research in behavior analysis. *Journal of Applied Behavior Analysis*, *36*, 415–419.

Madden, G. J., Bickel, W. K., & Jacobs, E. A. (2000). Three predictions of the economic concept of unit price in a choice context. *Journal of the Experimental Analysis of Behavior*, *73*, 45–64.

Madden, G. J., Dake, J. M., Mauel, E. C., & Rowe, R. R. (2005). Labor supply and consumption of food in a closed economy under a range of fixed- and random-ratio schedules: Tests of unit price. *Journal of the Experimental Analysis of Behavior*, *83*, 99–118.

Madden, G. J., Smethells, J. R., Ewan, E. E., & Hursh, S. R. (2007). Tests of behavioral-economic assessments of relative reinforcer efficacy: Economic substitutes. *Journal of the Experimental Analysis of Behavior*, *87*, 219–240.

Pace, G. M., Ivancic, M. T., Edwards, G. L., Iwata, B. A., & Page, T. J. (1985). Assessment of stimulus preference and reinforcer value with profoundly retarded individuals. *Journal of Applied Behavior Analysis*, *18*, 249–255.

Peterson, L., Homer, A. L., & Wonderlich, S. A. (1982). The integrity of independent variables in behavior analysis. *Journal of Applied Behavior Analysis*, *15*, 477–492.

Raslear, T. G., Bauman, R. A., Hursh, S. R., Shurtleff, D., & Simmons, L. (1988). Rapid demand curves for behavioral economics. *Animal Learning & Behavior*, *16*, 330–339.

Ringdahl, J. E., Kitsukawa, K., Andelman, M. S., Call, N., Winborn, L., Barretto, A., et al. (2002). Differential reinforcement with and without instructional fading. *Journal of Applied Behavior Analysis*, *35*, 291–294.

Roane, H. S., Call, N. A., & Falcomata, T. S. (2005). A preliminary analysis of adaptive responding under open and closed economies. *Journal of Applied Behavior Analysis*, *38*, 335–348.

Roane, H. S., Falcomata, T. S., & Fisher, W. W. (2007). Applying the behavioral economics principle of unit price to DRO schedule thinning. *Journal of Applied Behavior Analysis*, *40*, 529–534.

Roane, H. S., Lerman, D. C., & Vorndran, C. M. (2001). Assessing reinforcers under progressive schedule requirements. *Journal of Applied Behavior Analysis*, *34*, 145–167.

Roane, H. S., Vollmer, T. R., Ringdahl, J. E., & Marcus, B. A. (1998). Evaluation of a brief stimulus preference assessment. *Journal of Applied Behavior Analysis*, *31*, 605–620.

Roscoe, E. M., Iwata, B. A., & Kahng, S. (1999). Relative versus absolute reinforcement effects: Implications for preference assessments. *Journal of Applied Behavior Analysis*, *32*, 479–493.

Tustin, R. D. (1994). Preference for reinforcers under varying schedule arrangements: A behavioral economic analysis. *Journal of Applied Behavior Analysis*, *27*, 597–606.

Tustin, R. D. (2000). Revealed preference between reinforcers used to examine hypotheses about behavioral consistencies. *Behavior Modification*, *24*, 411–424.

Vaughn, M. E., & Michael, J. L. (1982). Automatic reinforcement: An important but ignored concept. *Behaviorism*, *10*, 217–227.

Vollmer, T. R., Borrero, J. C., Wright, C. S., Van Camp, C., & Lalli, J. S. (2001). Identifying possible contingencies during descriptive analyses of severe behavior disorders. *Journal of Applied Behavior Analysis*, *34*, 269–287.

Zhou, L., Iwata, B. A., Goff, G. A., & Shore, B. A. (2001). Longitudinal analysis of leisure-item preferences. *Journal of Applied Behavior Analysis*, *34*, 179–184.

Zhou, L., Iwata, B. A., & Shore, B. A. (2002). Reinforcing efficacy of food on performance during pre- and postmeal sessions. *Journal of Applied Behavior Analysis*, *35*, 411–414.

Received June 15, 2007
Final acceptance March 3, 2008
Action Editor, Kenneth Silverman