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PREFERENCE FOR REINFORCERS UNDER VARYING SCHEDULE ARRANGEMENTS: A BEHAVIORAL ECONOMIC ANALYSIS

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The field of behavioral economics combines concepts from economics and operant conditioning to examine the influence of schedules or price on preference for reinforcers. Three case studies are reported in which behavioral economic analyses were used to assess relative preference for reinforcers shown by people with intellectual disabilities when schedule requirements varied. The studies examined (a) preference for different reinforcers, (b) substitutability of reinforcers, and (c) changes in preference as a function of schedule requirements.

DESCRIPTORS: preference, behavioral economics, substitutability of reinforcers, durability of reinforcers, potency of reinforcers

As our conceptualization of the nature of reinforcement has expanded, new methods have been introduced to measure preference among reinforcers. Reviews of the developing conceptualizations of reinforcers have been provided by both L. Green and Freed (1993) and Timberlake and Farmer-Dougan (1991). Meehl (1950) used a transsituational approach to identify reinforcers; assuming that reinforcers might be generalizable, an event that functions as a reinforcer in one situation might function as a reinforcer in other situations. Premack (1959, 1965) used a quantitative approach to identify reinforcers, predicting the potential reinforcing effect of responses from the differential probabilities (or rates) of the responses when they were freely available. A response-deprivation principle emphasizes that a contingent event will have a reinforcing effect only if the schedule reduces the rate of that event below the free-operant level (Allison, 1993; Timberlake, 1980; Timberlake & Allison, 1974). Others have used a variety of choice procedures to identify preference among reinforcers both in experimental situations (Herrnstein, 1970) and in applied situations (Fisher et al., 1992; Pace, Ivancic, Edwards, Iwata, & Page, 1985).

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Methods currently used in applied behavior analysis for assessing preference among reinforcers focus on situations in which reinforcers are either freely available or are contingent on low schedule requirements (Datillo, 1986; Ferrari & Harris, 1981; Pace et al., 1985; Quilitch, Christophersen, & Risley, 1977; Wacker, Berg, Wiggins, Muldoon, & Cavanagh, 1985). These approaches are based on the implicit assumption that measures of preference taken in conditions of low schedule constraint will generalize as schedule requirements increase, because reinforcers will be potent and durable in maintaining a high number of responses when schedule requirements increase. However, the results of several studies cast doubt on this assumption. Both Rincover, Newsom, Lovaas, and Koegel (1977), and C. Green, Reid, Canipe, and Gardner (1991) found that some reinforcers became ineffective when schedule requirements increased.

The effects of schedule requirements on choice have been of continuing interest in basic research. Two approaches to measure preference under varying schedule arrangements have been used: the matching principle (Herrnstein, 1970), and behavioral economic approaches (Hursh, 1984; Morgan & Tustin, 1992; Rachlin, Battalio, Kagel, & Green, 1981; Tustin & Morgan, 1985). Both Neef, Mace, Shea, and Shade (1992) and L. Green and Freed (1993) noted that, although the matching principle is applicable when alternative reinforcers are qualitatively similar, its ability to predict choice between qualitatively different reinforcers may be limited. By contrast, measures of preference used in the field of behavioral economics are applicable when reinforcers are qualitatively different (Rachlin et al., 1981), so data from economic analyses of schedule effects may be particularly relevant to applied behavior analysts.

In behavioral economics, reinforcement is conceptualized as an exchange, in which responding is "exchanged" for reinforcers. The schedule sets the rate of exchange between responses and reinforcers, and can be viewed as setting either the "price" of a reinforcer or the "pay rate" earned by a worker. The price of a reinforcer is the number of instrumental responses (I) required to earn a unit of the reinforcer (R), so price $= I/R$. The pay rate is the number of reinforcers obtained per unit of instrumental responding, so pay rate $= R/I$, which is the inverse of price. When fixed-ratio (FR) schedules are used, the relation between I and R is set by the schedule requirement (Hursh, 1984). The concept of price is used in the economic theory of demand for reinforcers (Lea, 1978; Rachlin et al., 1981), whereas the concept of pay rate is used in the economic theory of labor supply (Battalio, Kagel, & Green, 1979).

Preference for reinforcers can be measured using reinforcer-demand functions, which are descriptive measures showing changes in rate of reinforcement as schedule requirements increase (Hursh, 1984; Lea & Roper, 1977). Typically, subjects obtain lower rates of reinforcement as the schedule requirement increases, producing a negative slope to a reinforcer-demand function. A steep negative slope in a demand curve occurs if the subject does not maintain the free-operant rate of reinforcement as the schedule requirement increases, and a flatter demand curve occurs when a subject does maintain rate of reinforcement while the schedule requirement increases. A flatter demand curve is assumed to reflect a "more highly valued" or preferred reinforcer, because rate of reinforcement is maintained when the schedule requirements increase (Kagel, Battalio, Green, & Rachlin, 1980).

Demand curves may also differ in their intercept, which describes the rate of reinforcement obtained when reinforcers are freely available. The intercept corresponds to the free-operant measure recommended by Premack (1959). A reinforcer whose demand curve has a higher intercept is assumed to be more highly valued, because more units are obtained when constraints are low. Note that the whole shape of a demand curve provides more information about changes in rate of reinforcement than does a single point estimate such as the intercept.

An alternative but equivalent measure of preference for reinforcers is obtained using work-rate functions (Allison & Boulter, 1982; Staddon, 1979, 1980), which describe changes in rate of responding (or work emitted) as the schedule requirement increases. Hursh (1984) outlined relations between demand functions and work-rate functions.

Demand curves can be generated either in a single schedule situation in which only one reinforcer is available or in a concurrent schedule situation in which alternative reinforcers are available. When a single schedule of reinforcement is available, points of interest are the free-operant reinforcement rate and the degree to which the free-operant rate is maintained when the schedule requirement increases. When two schedules of reinforcement are concurrently available and schedule requirements change, subjects can substitute (or exchange) reinforcers available from the two schedules. The substitutability of alternative reinforcers can be assessed using an experimental procedure in which the requirement on one schedule is kept constant while the requirement on the second schedule is varied (Kagel et al., 1980). Relations between reinforcers are inferred from changes in the rate of reinforcement with a constant price when the price of an alternative reinforcer is varied (Rachlin & Krasnoff, 1983). A distinction is made between two types of demand curves. An "own-price" demand curve shows the rate of reinforcement plotted against its own price. A "cross-price" demand curve shows rate of reinforcement with a constant price plotted against the changing price of another reinforcer.

The relationship between two concurrently available reinforcers can be deduced from the shape of the cross-price demand curve. Two reinforcers are said to be *substitutes* if the rate of reinforcement from a schedule with a constant requirement changes in the opposite direction to the rate of reinforcement from the schedule with a changing requirement. If two reinforcers are substitutes, then the cross-price demand curve has a positive slope. Two reinforcers are said to be *complements* if the rate of reinforcement from the constant schedule changes in the same direction as rate of the other reinforcer, producing a cross-price demand curve with a negative slope (Rachlin, Green, Kagel, & Battalio, 1976; Rachlin & Krasnoff, 1983). The degree of substitutability or complementarity is measured from the slope of the function.

Economic analyses have the potential to make several contributions to applied behavior analysis. Own-price demand curves may be used to measure the effectiveness of a single reinforcer in maintaining responding when schedule requirements increase. Cross-price demand curves can be used to measure the relation between alternative reinforcers as substitutes or complements. Because demand curves measure the relation between responding and reinforcement when contextual variables change, they provide a basic tool for examining how performance is affected by context.

The primary independent variable in behavioral economics is the schedule requirement. However, few studies have examined the effects of changing schedule requirements when people work for reinforcers (e.g., Mullins & Rincover, 1985). The present study illustrates the use of behavioral economic methods for analyzing data gathered when both reinforcers and schedule arrangements were varied.

METHOD

Subjects

Three individuals with an intellectual disability participated as subjects. Subject 1 was a 23-year-old man with a moderate degree of intellectual disability. Subject 2 was a 22-year-old man with a moderate degree of intellectual disability and autism. Subject 3 was a 21-year-old man with severe intellectual disability and autism. All subjects understood simple instructions.

Procedure

Subjects responded on either of two buttons on a joystick attached to a computer, which they had previously used to play simple computer games shown on a TV screen. Daily sessions were conducted in a room in a vocational center.

At the beginning of the study, subjects were given the following instructions:

> Each day you will be able to play a computer game. If you press one of these buttons, the computer will light up (go whizz, go off). You might have to press the button lots of times before it goes off. A card will show you how many times you might have to press the button. If the card is long, you will have to press the button lots of times. You can start playing the game when you are ready.

The computer recorded responses and either signaled that reinforcers had been earned or generated and delivered reinforcers. Sessions continued until a prearranged number of reinforcers had been delivered or 5 min had elapsed without any response being emitted, whichever occurred first. The numbers of reinforcers available per session were 25 for Subject 1, 25 for Subject 2, and 40 for Subject 3. More reinforcers were provided for Subject 3 because requirements were very low on both schedules during his initial sessions. An observer monitored whether the computer functioned as expected until the first five reinforcers had been delivered in each session. Agreement between responses recorded by the computer and by the observer was 100%.

Subjects were exposed to different reinforcers and schedule arrangements. Five reinforcers were used: visual stimuli, auditory stimuli, complex sensory stimuli, constant color, and social attention. Reinforcers were presented for 5 s unless otherwise stated. Visual stimuli were continuously changing colors and patterns generated by the computer. Auditory stimuli were musical tones generated by the computer. Complex sensory stimuli combined

Table 1
Reinforcing Stimuli and Their Associated Schedule Arrangements

Subject	Series	Reinforcer	Arrangement	Schedule
1	1	complex sensory	single	varied
	2	attention	single	varied
2	1	a. visual	concurrent	FR 5
	1	b. auditory		varied
2	2	a. visual	concurrent	FR 5
	2	b. attention		varied
3	1	a. constant color	concurrent	varied
		b. complex sensory		varied

the visual and auditory stimuli above. In constant color, the computer screen remained one bright color for 5 s. Social attention was cued by the computer, and involved the observer (who had previously worked with the subject) smiling at, nodding at, and praising the subject for 3 s.

Fixed-ratio schedules of reinforcement were used for all subjects. The requirement on some schedules remained constant at FR 5 across sessions, whereas the requirements on other schedules were varied across sessions, either progressively increasing or decreasing. When requirements were varied, they were FR 1, FR 2, FR 5, FR 10, and FR 20. Each schedule was maintained for one session and was increased in the next session, so that an increasing progression consisted of FR 1 on Monday, FR 2 on Tuesday, FR 5 on Wednesday, and so on. All schedules were presented three times each, increasing progressively from FR 1 to FR 20, then decreasing progressively from FR 20 to FR 1, and then increasing progressively. Schedule requirements were signaled by placing a card near the response key, with the card's length (varying from 2 cm to 40 cm) being proportional to the requirement.

Subject 1 participated in two series in which schedules were presented singly, with the reinforcers consisting of complex sensory stimuli delivered on a varied schedule in Series 1 and attention delivered on a varied schedule in Series 2. Subject 2 participated in two series, both involving two schedules presented concurrently. In Series 1, Subject 2 responded for a choice of visual reinforcers always delivered on an FR 5 schedule and auditory stimuli delivered on a varied schedule. In Series 2, Subject 2 worked for a choice of visual stimuli on an FR 5 schedule and attention delivered on a varied schedule. Subject 3 participated in one series of concurrent schedules, for a choice of constant color delivered on a varied schedule and complex sensory stimuli also delivered on a varied schedule. For Subject 3, requirements on both schedules changed together (e.g., both were FR 1, then both were FR 2, etc.).

The reinforcers and schedule arrangements are summarized in Table 1. For all subjects, dependent variables were the numbers of reinforcers obtained and responses emitted on each schedule per session.

RESULTS

Subject 1

Figure 1 presents the data for Subject 1 in three alternative and equivalent ways. The top panel shows the schedule lines on a graph in which reinforcers obtained per session are plotted against responses emitted per session. The fixed-ratio schedules are represented by straight lines drawn through the origin. The slope of the schedule line is determined by the requirement of the schedule, with a steeper slope representing a lower schedule requirement. This graph shows the points on each schedule line chosen by Subject 1 (i.e., the combinations of responses and reinforcers chosen from all of the combinations made available by the schedule). An assessment of data points against the reinforcement axis shows that Subject 1 obtained the maximum number of both reinforcers when an FR 1 schedule was used. As schedule requirements increased, Subject 1 earned the complex sensory reinforcer at a higher level than the attention reinforcer. An assessment of data points against the response axis shows that as the schedule requirement increased, Subject 1 increased responding more for the complex sensory reinforcer than for the attention reinforcer.

The middle and bottom panels show the same data drawn using different axes. The middle panel shows obtained reinforcers plotted against the schedule requirement (price), yielding demand curves for each reinforcer. The bottom panel shows responses plotted against the schedule requirement (pay rate), yielding work-rate functions for each reinforcer.

In the middle panel of Figure 1, demand curves were formed by joining data points obtained under each schedule requirement. Demand curves for both reinforcers have negative slopes. The demand curve for the complex sensory reinforcer is higher than the demand curve for the attention reinforcer, has a shallower slope, and has about the same intercept (the intercept is similar for the two reinforcers because both were obtained at the same rate when the requirement was FR 1). As the requirement increased to FR 20, the attention reinforcers earned fell more rapidly than did the complex sensory reinforcers, suggesting that the complex sensory reinforcer was preferred under increasing schedule requirements, but not when both reinforcers were delivered under FR 1 schedules.

In the bottom panel of Figure 1, work-rate functions are formed by joining response data points obtained from each schedule requirement. Work-rate functions for both reinforcers are bitonic; responding increased and then decreased as the schedule requirement increased. Work rate was higher for the complex sensory reinforcer than for the attention reinforcer at most schedule requirements, with the peak work rate for the complex sensory reinforcer occurring at a higher schedule requirement. This pattern shows that Subject 1 emitted

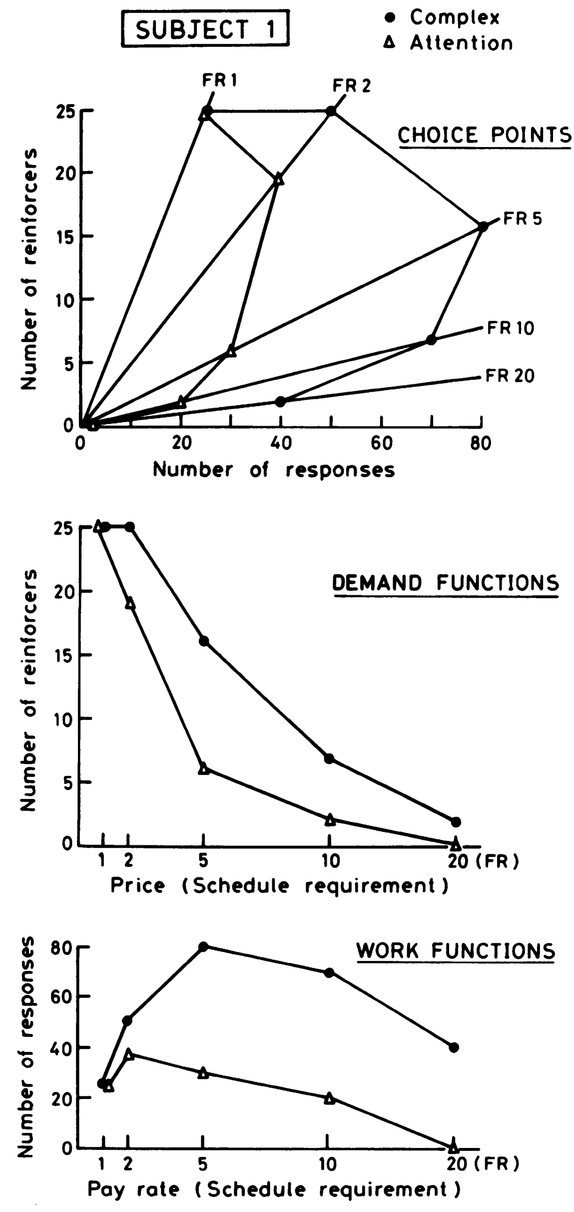

Figure 1. Data points for Subject 1 are shown in three ways, when schedules were presented singly. The top panel shows median data points on each schedule line; the axes are numbers of reinforcers per session and numbers of responses per session. The middle panel shows demand functions (reinforcers per session are plotted against FR schedule requirements). The bottom panel shows work-rate functions (responses per session are plotted against FR schedule requirements).

higher response rates when the complex sensory reinforcer was available than when the attention reinforcer was available. The highest response rate for the complex sensory reinforcer occurred when the schedule requirement was FR 5, whereas the highest response rate for the attention reinforcer occurred when the requirement was FR 2. Because the complex sensory reinforcer both maintained a higher response rate overall and produced a peak response rate under a higher schedule requirement, it is assumed to be more potent.

In summary, the data for Subject 1 were analyzed in three equivalent ways: as choice points on schedule lines, as own-price demand curves, and as work-rate functions. The demand functions and work-rate functions showed similar features for the two reinforcers. Both reinforcers produced negatively sloped demand curves and bitonic work-rate functions. The subject's choice of the reinforcers was revealed from the relative shapes of both the demand functions and the work-rate functions. Demand curves were interpreted by assuming that the preferred reinforcer was the one whose rate was maintained when requirements increased. Work-rate functions were interpreted by assuming that the preferred reinforcer was the one that maintained a higher response rate when schedule requirements increased, and whose peak occurred at a higher schedule requirement. In this case, relative preference between the reinforcers remained constant as schedule requirements increased.

Subject 2

Reinforcement rates obtained by Subject 2 in the two series of concurrent schedules are shown as demand curves in Figure 2, which shows the numbers of each reinforcer plotted against the requirement for the varied schedule (auditory and attention reinforcers). The schedule requirements for visual reinforcers remained constant at FR 5. Variability in data points across the three sessions at each schedule value is shown by highlighting the median points, with the range indicated by vertical lines.

Figure 2 shows both own-price and cross-price demand curves. The demand curves for the auditory stimuli and attention are own-price demand curves because the rates of reinforcement for these stimuli are plotted against their own schedule requirements. The demand curves for the visual reinforcers are cross-price demand curves because the rates of these reinforcers are plotted against the schedule requirements for an alternative reinforcer.

The left panel of Figure 2 shows that increasing the schedule requirement produced a sharp decrease in number of the auditory reinforcers earned, giving a demand curve with a steep negative slope. The reduction in auditory reinforcers earned was accompanied by a corresponding sharp increase in the number of visual reinforcers earned, yielding a cross-price demand curve with a steep positive slope. The right panel of Figure 2 shows that increasing the schedule requirement produced a gradual decrease in the numbers of attention reinforcers earned, yielding an own-price demand curve with a shallow negative slope. The number of visual reinforcers earned increased gradually, giving a cross-price demand curve with a shallow positive slope.

The shape of the cross-price demand curve reflects the degree of substitutability of the alternative reinforcers. In both cases, cross-price demand curves had positive slopes, showing that the concurrently available reinforcers were substitutes rather than complements. The steeper slope in the cross-price demand curve for the visual reinforcer when the alternative was an auditory reinforcer rather than an attention reinforcer suggests that the two sensory reinforcers were more substitutable in this case.

Subject 3

Data for the two reinforcers earned by Subject 3 are shown in Figure 3 as own-price demand curves. Under the FR 1 schedule requirement, the constant color reinforcer was obtained at a higher rate than the complex sensory reinforcer. As requirements on both schedules increased together, the number of constant color reinforcers earned decreased, while the number of complex sensory reinforcers earned first increased and then decreased. The demand curves cross near the point where both schedule requirements were FR 2.

A higher demand curve for the constant color reinforcer at the point at which the schedule re-

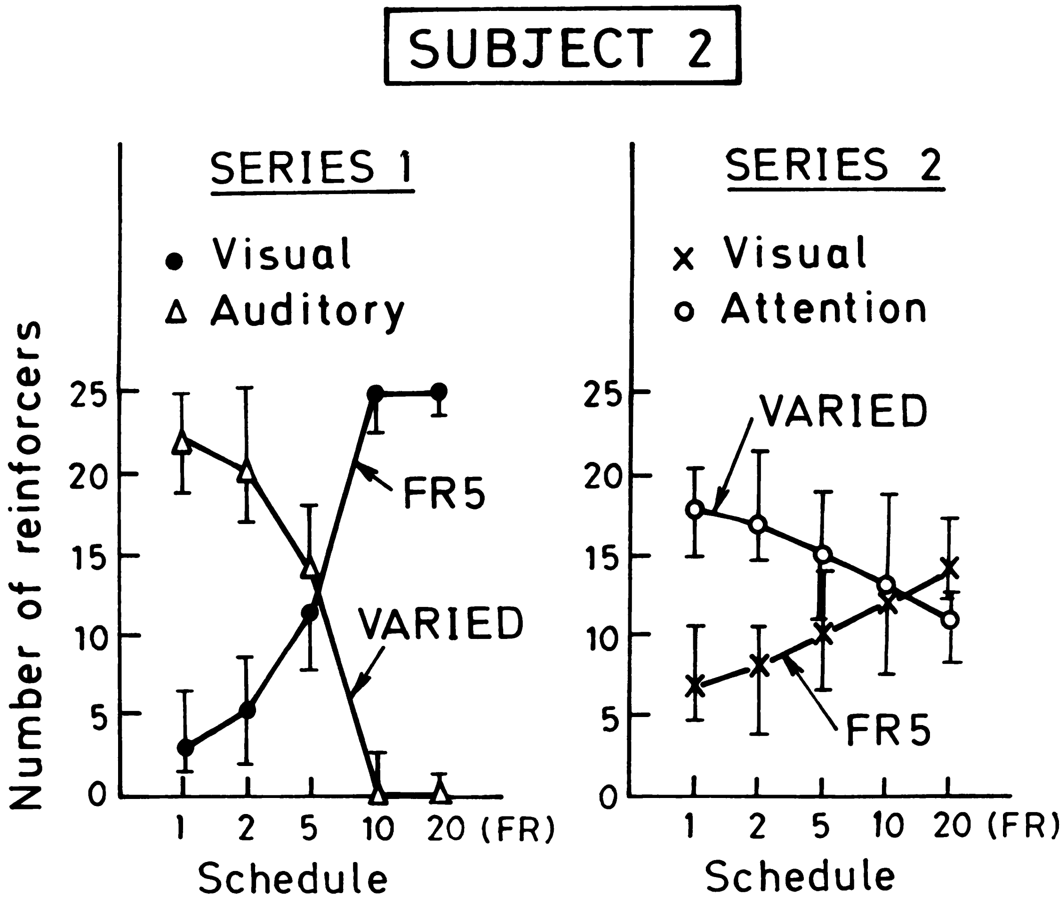

Figure 2. Two pairs of demand functions are shown for Subject 2, obtained from concurrent schedules. Visual stimuli were presented under an FR 5 schedule, with either auditory stimuli (Series 1) or attention (Series 2) presented under a varied schedule.

quirement was low indicates that the constant color reinforcer was preferred to the complex sensory reinforcer when schedule constraints were low. The crossing of demand curves shows that preference reversed, so that the complex sensory reinforcer became preferred when schedule requirements increased.

DISCUSSION

Three case studies demonstrated the application of behavioral economic methods for analyzing preference between reinforcers when schedule requirements change. The first case study demonstrated that own-price demand functions can be used to measure preference when schedule requirements increase. The relationship between demand curves and work-rate functions was illustrated. In this case, relative preference between the reinforcers remained constant when schedule requirements increased. The second case study used cross-price demand curves to examine the degree of substitutability of two pairs of reinforcers. The demand for a reinforcer was found to be influenced by the nature of the alternative reinforcer, with lower reinforcement rates being maintained on the constant schedule when the alternative reinforcer was more substitutable. The third case study used own-price demand curves to examine preference when schedule requirements increased together for two reinforcers, and showed a reversal of preference: The reinforcer that was preferred when schedule requirements were low was

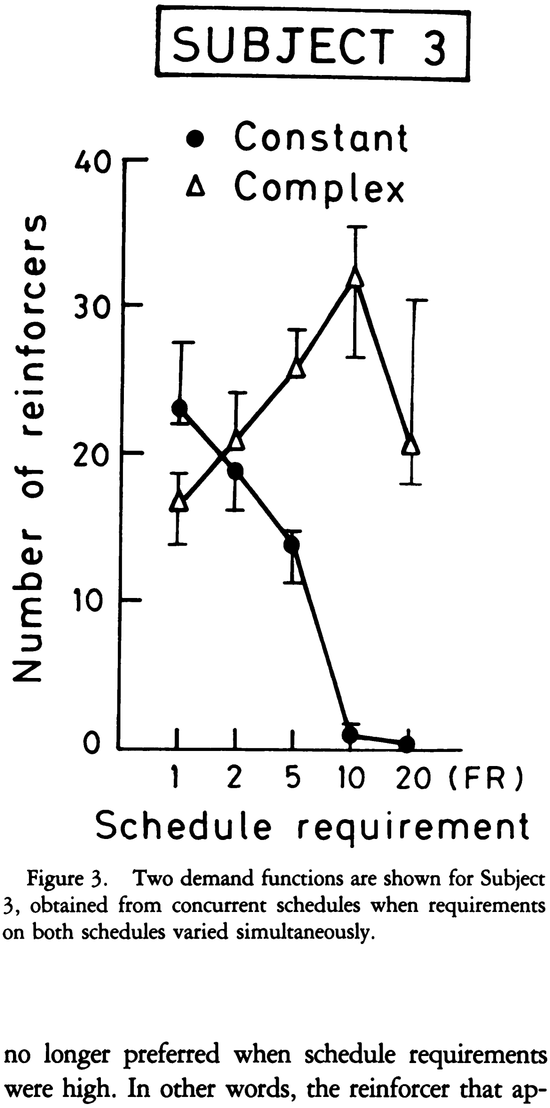

Figure 3. Two demand functions are shown for Subject 3, obtained from concurrent schedules when requirements on both schedules varied simultaneously.

no longer preferred when schedule requirements were high. In other words, the reinforcer that appeared to be more potent when assessed under the FR 1 condition proved not to be durable when schedule constraints increased.

These results showed that the potency of reinforcers in maintaining responding was not a static property of the reinforcing events, but was influenced by several variables, including the schedule requirement, the availability of alternative reinforcers, and the nature of the alternative reinforcer. Own-price demand functions were used to measure the potency of reinforcers when schedule requirements changed, both when schedules were presented singly and when schedules were presented concurrently. The ability of reinforcers to maintain responding was assessed from the relative shapes of own-price demand curves.

The relationship between two alternative reinforcers was examined with Subject 2 using cross-price demand curves. Cross-price demand curves provide a tool that can be used in applied behavior analysis to examine interactions between qualitatively different reinforcers. Pairs of reinforcers that generate positively sloped cross-price demand curves were interpreted as being substitutes. The degree of substitutability was inferred from the relative slopes of cross-price demand curves.

The shapes of demand curves obtained in these studies are consistent with functions obtained using nonhuman subjects (DeGrandpre, Bickel, Hughes, Layng, & Badger, 1993; Hursh, 1980), as were the shapes of work-rate functions (Battalio et al., 1979; Baum, 1993; Staddon, 1979). Thus, it appears that basic research on behavioral economics and reinforcer substitutability may have some relevance for applied work.

The present data showed that demand curves provide an objective measure of "preference" in terms of the price a subject will pay to obtain reinforcers, where price is measured by level of responding. Because shapes of demand curves were shown to be responsive to objective independent variables, demand curves might be useful tools for examining how contextual variables influence preference for reinforcers.

Although the present case studies are only illustrative, they raise a number of implications for applied behavior analysis. The finding that preference may reverse as schedule requirements increase is important, because it casts doubt on the viability of assessing preference only in conditions of low constraint when reinforcers are freely available, and of assuming that measures of preference will generalize across schedule requirements. In the third case study, information about preference gathered in conditions of low schedule constraint did not predict preference when schedule constraints increased. Further work is required to determine how commonly preferences reverse and why preferences reverse. One implication of this finding is that, if the aim of assessing the potency of reinforcers is to identify reinforcers that are durable when schedule requirements increase, then assessment procedures may need to be conducted under these conditions.

These studies should be viewed as illustrating an approach, rather than as establishing firm findings. Due to a number of limitations in design, caution is needed when interpreting specific results. Because only single subjects were used, the generality of conclusions has not been tested. Some experimental procedures have not been used extensively with humans, including the use of cards to signal schedule requirements and the use of progressive changes in schedule requirements over sessions. A number of additional issues remain to be examined in further research, such as the influence of response variables and the stability of preference over time.

Behavioral economic approaches introduce distinctive conceptualizations that may assist applied behavior analysts in at least four ways. First, because this economic approach deals directly with schedules, information is gathered about rates of responding that will be supported by a reinforcer. This may circumvent having to "guess" about a suitable exchange rate and later finding that a "reinforcer" did not "reinforce" because a client would not emit the number of responses required by the schedule. Second, information can be gathered about whether an event functions as a generalized reinforcer that is highly substitutable and maintains a wide range of responses, or whether different types of response are better maintained by different reinforcers. For example, is a mother's praise effective in maintaining a wide variety of responses from a young man, or is it the case that praise from the father maintains working on a car, praise from a male friend maintains sporting activity, and praise from a girlfriend maintains self-care tasks such as hair grooming? A third issue is the extent to which a reinforcer maintains similar rates of responses that require similar levels of effort. For example, does a given payment have similar effects in maintaining two tasks, such as cleaning dishes and cleaning a toilet? If a reinforcer maintains two responses at different rates, how will the demand curves from the two responses be affected? The fourth issue involves the substitutability of two reinforcers. Assume that a teacher wants to withhold praise until a student performs a certain task, but is concerned that the student will substitute attention from peers in place of attention from the teacher. The behavioral economic approach provides a method for assessing the substitutability of the two reinforcers and for predicting the effect of withholding a given reinforcer.

In summary, the present results showed that economic demand curves provide valuable information about preference when schedule requirements change. The demand curve thus may be used by applied behavior analysts to examine a number of questions about how subjects exchange responses for reinforcers, especially when reinforcers are qualitatively different.

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