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HUMANS' CHOICES IN SITUATIONS OF TIME-BASED DIMINISHING RETURNS

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Three experiments examined adult humans' choices in situations with contrasting short-term and long-term consequences. Subjects were given repeated choices between two time-based schedules of points exchangeable for money: a fixed schedule and a progressive schedule that began at 0 s and increased by 5 s with each point delivered by that schedule. Under "reset" conditions, choosing the fixed schedule not only produced a point but it also reset the requirements of the progressive schedule to 0 s. In the first two experiments, reset conditions alternated with "no-reset" conditions, in which progressive-schedule requirements were independent of fixed-schedule choices. Experiment 1 entailed choices between a progressive-interval schedule and a fixed-interval schedule, the duration of which varied across conditions. Switching from the progressive- to the fixed-interval schedule was systematically related to fixed-interval size in 4 of 8 subjects, and in all subjects occurred consistently sooner in the progressive-schedule sequence under reset than under no-reset procedures. The latter result was replicated in a second experiment, in which choices between progressive- and fixed-interval schedules were compared with choices between progressive- and fixed-time schedules. In Experiment 3, switching patterns under reset conditions were unrelated to variations in intertrial interval. In none of the experiments did orderly choice patterns depend on verbal descriptions of the contingencies or on schedule-controlled response patterns in the presence of the chosen schedules. The overall pattern of results indicates control of choices by temporally remote consequences, and is consistent with versions of optimality theory that address performance in situations of diminishing returns.

Key words: choice, optimality theory, self-control, scales of analysis, fixed schedules, progressive schedules, verbal-nonverbal relations, key press, adult humans

We speak of "self-control" when long-term consequences of action outweigh short-term consequences. This balancing of immediate against temporally distant events is implicit in many issues concerning health and welfare; it is also a key relationship in cost/benefit interpretations of human and nonhuman behavior, such as optimality theory in behavioral ecology and maximization theory in economics. Experimental analyses of self-control have come to be identified with a procedure in which immediate access to a small reinforcer is pitted against delayed access to a larger amount of that reinforcer (Mischel, 1966; Rachlin & Green, 1972). Selecting the larger delayed reinforcer is taken as evidence of "self-control," and can be viewed in terms consistent with maximization principles; selecting the smaller immediate reinforcer is taken as evidence of "impulsiveness," or of sensitivity to consequences within a narrower time frame.

Some notable differences between human and nonhuman performances have been reported with this type of self-control procedure, with pigeons' choices typically showing far greater sensitivity to delay than adult humans' choices (see review by Logue, 1988). In a majority of cases, pigeons' choices are strongly biased toward immediate consequences, whereas humans' choices are biased toward alternatives yielding maximal reinforcement rates (Belke, Pierce, & Powell, 1989; Logue, Peña-Correal, Rodriguez, & Kabela, 1986).

Another set of procedures for assessing sensitivity to immediate versus long-term conse-

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quences was introduced by Hodos and Trumbule (1967). In recent years, a range of species have been studied on these procedures, including chimpanzees in the original Hodos and Trumbule study, rhesus monkeys (Hineline & Sodetz, 1987), pigeons (Hackenberg & Hineline, 1992; Wanchisen, Tatham, & Hineline, 1988), and humans (Wanchisen, Tatham, & Hineline, 1992). The basic procedures are characterized by situations of diminishing returns, whereby persistence in one activity yields a steadily declining rate of gain. In the Hodos and Trumbule procedure, and in most subsequent replications, these diminishing returns were arranged by means of a progressive-ratio (PR) schedule of reinforcement, the requirements of which increased by 20 responses after delivery of each reinforcer. The PR option was opposed by a fixed-ratio (FR) schedule, the requirements of which remained constant within individual sessions but varied across blocks of sessions. Hackenberg and Hineline (1992) extended the procedures to time-based schedules, providing pigeons with recurrent choices between fixed-interval (FI) schedules and a progressive-interval (PI) schedule, thereby dissociating time from response allocation as the basis of performance.

The chief point of interest in these procedures, whether response based or time based, is in patterns of switching from the progressive to the fixed schedule. In "no-reset" conditions, the progressive schedule escalates with successive reinforcers delivered by that schedule throughout a given session, regardless of when or how often the fixed schedule is chosen. Under these circumstances, short-term and long-term consequences both favor switching from the progressive to the fixed schedule at the equality point, defined as the position in the progressive-schedule sequence at which the requirements of the two schedules are equivalent. In "reset" conditions, the progressive schedule is reset to its minimum value with each reinforcer delivered by the fixed schedule. Under these circumstances, short-term consequences continue to favor switching at the equality point, but long-term consequences favor switching well in advance of that point, that is, when the requirements of the upcoming fixed schedule are far more stringent than the requirements of the progressive schedule that oppose it.

Despite the immediate costs of choosing a schedule with longer delays to reinforcement on the upcoming trial, both humans and nonhumans frequently do switch prior to the equality point on the reset procedure, revealing sensitivity to remote consequences. Hineline and Sodetz's (1987) monkeys switched from the PR to the FR at the approximate point that minimized the number of responses emitted per reinforcer, prompting the authors to consider the results within the framework of optimality theory. Switching patterns were consistent with the predictions of the marginal value theorem (Charnov, 1976), a version of optimality theory designed to address behavior in situations of diminishing returns—a feature common to many foraging environments. In these procedures, Charnov's formulation predicts patterns that maximize overall reinforcement rate; this coincides with views based on molar maximization (e.g., Houston & McNamara, 1988; Rachlin, Battalio, Kagel, & Green, 1981). Charnov's original theorem was based on a continuous gain curve, but subsequent versions (e.g., Pyke, 1978) have addressed performances on procedures like the present ones, in which the gain curve consists of a series of steps.

Pigeons (Hackenberg & Hineline, 1992; Wanchisen et al., 1988) also switched prior to the equality point, but often beyond that predicted by a strict application of the marginal value model. Across a range of both ratio and interval parameters, the pigeon data are well characterized by an account of schedule preference based on the cumulative effects of multiple delayed reinforcers (Shull & Spear, 1987; Shull, Spear, & Bryson, 1981). According to this view, each of several reinforcers makes an independent contribution to the effectiveness of a particular series of reinforcers. Reinforcers remote from a choice are weighted less heavily than more proximal reinforcers, according to a temporal discounting function that specifies how sharply delayed events decline in their effectiveness. Specifically, the reinforcing effectiveness of a particular sequence of reinforcers is related to the reciprocals of the delays to each reinforcer in the series, all timed in relation to a single choice point. These relations have been formalized in the following way (Mazur & Vaughan, 1987; McDiarmid & Rilling, 1965):

$$V = \sum_{i=1}^{n} \frac{1}{D_i}, \qquad (1)$$

where V is the value, or reinforcing effectiveness, of a particular option that includes a series of consequences, D_i is the delay between a choice and a reinforcing consequence i, and n is the number of reinforcers in the series. Unlike more conventional methods of averaging interreinforcement intervals, the relevant intervals here are all timed from a single point, namely the choice response.

The number of reinforcers included in the series depends on the level at which orderly relations are apparent. When $n = 1$, behavior is controlled by its most immediate consequences; when n is very large, the predictions of this model converge on those of optimization models, such as Charnov's (1976) marginal value theorem. To account for the pigeon data (Hackenberg & Hineline, 1992; Wanchisen et al., 1988), it has been necessary to include four reinforcers in the equation, which implies that current choices are affected by events distributed over a span of four choice trials. Although these results suggest a longer time frame than the "impulsive" patterns of trial-to-trial choices normally reported in nonhumans, they do indicate a greater sensitivity to delay than humans' choices on conventional self-control procedures. The latter are fairly well described by literal applications of optimization principles (Logue, 1988). (By literal application of optimization principles, we mean predictions based on overall reinforcement rates, where those rates are computed as arithmetic means of the interreinforcement intervals.)

In accounting for such human–nonhuman differences, an appeal is frequently made to human verbal functioning, which is said to modulate sensitivity to programmed reinforcement variables (Bentall & Lowe, 1987). Even when explicit instructions are not provided, humans may engage in collateral verbal behavior that interacts with nonverbal responding (Laties & Weiss, 1963). For example, subjects in Logue et al.'s (1986) study reported, in postsession questionnaires, that they followed "maximizing" rules based on counting or timing of relevant intervals. On the other hand, Wanchisen et al. (1992) found no evidence of systematic relations between nonverbal choice patterns and postsession verbal reports, despite orderly relations between those choice patterns and programmed consequences. On the reset procedure, Wanchisen et al.'s human subjects, like nonhumans, often switched prior to the equality point, but the specific parameters used in the study did not permit a definitive test of optimization against Shull and Spear's (1987) delay-based account (Equation 1).

The present research examined humans' choices between fixed and progressive time-based schedules, in an attempt to evaluate further species differences in sensitivity to remote consequences, and to assess the descriptive adequacy of optimality theory and Equation 1 as accounts of human choice. In Experiment 1, subjects were exposed to reset and no-reset procedures across variations in FI duration, including some values at which the models predict distinct switching patterns. In Experiment 2, the effects of response-independent and response-dependent scheduling of reinforcers were compared to assess the role of schedule-controlled response patterns in choices between those schedules. In Experiment 3, sensitivity to events within *and* between trials was examined, in an effort to distinguish more clearly between the predictions of optimality theory and Shull and Spear's (1987) formulation. In all three experiments, performances were maintained by points exchangeable for money, thereby providing a point of comparison with most previous studies in this domain. In an effort to clarify the role of verbal functioning in human choice, within-session verbal reports were also collected and analyzed in relation to nonverbal performances.

EXPERIMENT 1

This experiment examined humans' choices under reset and no-reset conditions across variations in FI size. Short-term consequences support switching from the PI to the FI at the equality point under both reset and no-reset procedures. Thus, if choices are controlled by their immediate consequences (e.g., delay to points on the upcoming trial), then one would expect reset and no-reset switch points to be approximately equal. Conversely, if behavior is controlled by patterns of consequences over multiple trials, as required by approaches more molar in emphasis, then one would expect switching to occur earlier in the PI sequence on the reset than on the no-reset procedure, despite the short-term costs such performance entails. Predictions of optimality and Equation 1 diverge with increases in FI duration.

METHOD

Subjects

Five female and 3 male adult volunteers participated in exchange for money. Subjects were recruited through advertisements posted on the University of Minnesota campus. The subjects, designated 2, 10, 22, 23, 24, 25, 30, and 49, were between the ages of 20 and 23, except for Subject 25, who was 45 years old. All but Subject 49 were concurrently enrolled in a general psychology course. Each subject agreed to participate in six sessions, approximately 90 min in length, with the understanding that total earnings would depend on performance. To encourage full participation, subjects received $1.50 per session in bonus earnings if they remained in the study for its full duration. The 7 subjects from the general psychology course were paid for all but their preliminary training session (for which they received course credit independent of their performance). Subject 49 was paid for all sessions, but earned a flat fee of $8.00 for the preliminary session. Overall earnings (including bonuses) ranged from $4.96 to $7.58 per hour (median = $6.47 per hour). Subjects did not receive any payments until participation was complete.

Apparatus

Subjects worked in a small room (2.6 m high by 2.5 m long by 2.4 m deep), where they were seated at a desk in front of an IBM-PC® microcomputer. Stimuli consisted of red and blue squares (8 cm by 8 cm) presented side by side (4 cm apart) on a color video monitor. Manipulanda consisted of the space bar and the two arrow keys on the keyboard, one of which pointed left (←), and the other right (→). The computer was connected to a printer in an adjacent room.

Procedure

The FI schedule was correlated with the red square throughout the experiment, and the PI schedule was correlated with the blue square. The procedure involved discrete choice points, during which the PI and FI schedules were simultaneously available. A red and a blue square were presented side by side during this choice phase. A single press of either arrow key initiated the requirements of the schedule whose stimulus appeared on the side to which the arrow pointed. For example, if the left square was blue and the right square red, pressing the ← key initiated the requirements of the blue (PI) schedule, whereas pressing the → key initiated the requirements of the red (FI) schedule. This choice response also disabled the alternate schedule and removed its accompanying square for the remainder of that trial; the square correlated with the chosen schedule remained on until the schedule requirements were satisfied by pressing the space bar. (Due to an auto-repeat function on the keyboard, schedule requirements could be satisfied by continuous holding of the space bar as well as by discrete presses on it.) Timing of scheduled intervals began with the choice response; the first press on the space bar after the scheduled interval elapsed produced a point, followed by an immediate return to the choice phase with both squares again present on the monitor. The procedure thus permitted frequent opportunities for switching to the alternative schedule. Point earnings were briefly signaled by an audible tone and by the incrementing of a counter ("SCORE = . . .") in the lower left corner of the video display. The left–right position of the red and blue squares was assigned randomly from trial to trial.

Each experimental session consisted of six 12-min blocks of choice trials, with a 1-min rest period separating each block. Just after each block but before the rest period, the following message appeared on the screen: "The best way to earn points is to . . . ." Subjects' responses to the query were entered directly on the keyboard and were printed in an adjacent room.

Fixed-interval requirements remained constant within each session (i.e., for six consecutive blocks of choice trials). Progressive-interval requirements began each 12-min block of trials at 0 s (the first press on the space bar following a PI choice produced a point) and increased in 5-s increments with each point delivered by that schedule. In no-reset sessions, PI requirements were independent of FI choices, escalating with successive PI choices within each block of trials. These sessions alternated with reset sessions in which FI choices,

Table 1

Sequence of conditions for subjects in Experiment 1. "R" and "N" refer to conditions run under reset and no-reset conditions, respectively. The number immediately following those labels denotes FI duration in seconds.

	Subject							
Session	2	10	22	23	24	25	30	49
1	R15	N15	R60	N60	R15	N60	R60	N15
2	N15	R15	N60	R60	N15	R60	N60	R15
3	R30	N30	R30	N30	R30	N30	R30	N30
4	N30	R30	N30	R30	N30	R30	N30	N60
5	R60	N60	R15	N15	R60	N15	R15	R30
6	N60	R60	N15	R15	N60	R15	N15	R60

in addition to producing a point on the FI schedule, also reset the PI schedule to 0 s.

Each subject was studied under reset and no-reset procedures for one (six-block) session each at FI values of 15 s, 30 s, and 60 s, with the exception of Subject 10, who was exposed to two successive nonresetting FI 60-s sessions by mistake (only the first session was included in the analysis). Based on some preliminary work, we had reason to expect stable responding in a single six-block session. With the exception of some of the conditions with 60-s FI schedules, this turned out to be a reasonable expectation (see below). Each subject was studied over a 2- to 3-week period, with sessions scheduled at approximately the same time of day. Table 1 shows the sequence of conditions for each subject. Four subjects (2, 10, 24, and 49) underwent an ascending sequence of FI values, and 4 others (22, 23, 25, and 30) experienced a descending sequence. The order of reset and no-reset sessions at each FI value was counterbalanced across subjects (with the exception of Subject 49; see Table 1).

Instructions. The following sheet of written instructions was placed on a desk next to the computer on which a subject worked:

> INSTRUCTIONS: PLEASE READ CAREFULLY. To choose a rectangle, use the ← or the → key. (Press only one key at a time). To earn points, use the space bar. Each point you earn is worth 4 cents. So, for example, if you earn 100 points, you will be paid $4.00. Each session will last for about 12 minutes, with a 1-minute rest period between sessions. During the rest period following the third session, you may leave the room if you so choose. At the end of each session, you will be asked to record your thoughts about the best way to earn points. When 6 sessions have been completed, you may leave. Of course, you may leave at any time during the exercise, in the event of an emergency. Please feel free to refer back to these instructions at any time. Thanks for your participation. (What is referred to as a "session" in the instructions is here called a "block.")

Each block of choice trials began with the message, "Press any key to begin," on the screen of the monitor, and ended with "The best way to earn points is to . . . ." The point counter in the lower left corner of the screen began each block of trials at 0. When PI requirements were at their minimal value, the inside of the blue square flashed.

Preliminary training. Subjects received one session of pretraining, consisting of five 12-min blocks of trials under a randomly assigned reset (Subjects 2, 22, 24, and 30) or no-reset (Subjects 10, 23, 25, and 49) contingency with FI 30 s. This session did not include queries between blocks of trials, as did all subsequent sessions. Instead, subjects were asked to write their guesses about the best way of earning points on a sheet of paper following the final block of trials. Each subject also received training in use of the keyboard just prior to the first experimental session. This consisted of typing a brief passage, then pressing a key that would later be used to initiate the rest period between blocks of trials. The purpose of these training exercises was merely to familiarize subjects with the manipulanda. The results of these training sessions are not included in the analysis.

Results and Discussion

Switching Patterns

The data of primary interest are switching patterns from the PI to the FI schedule. Figure

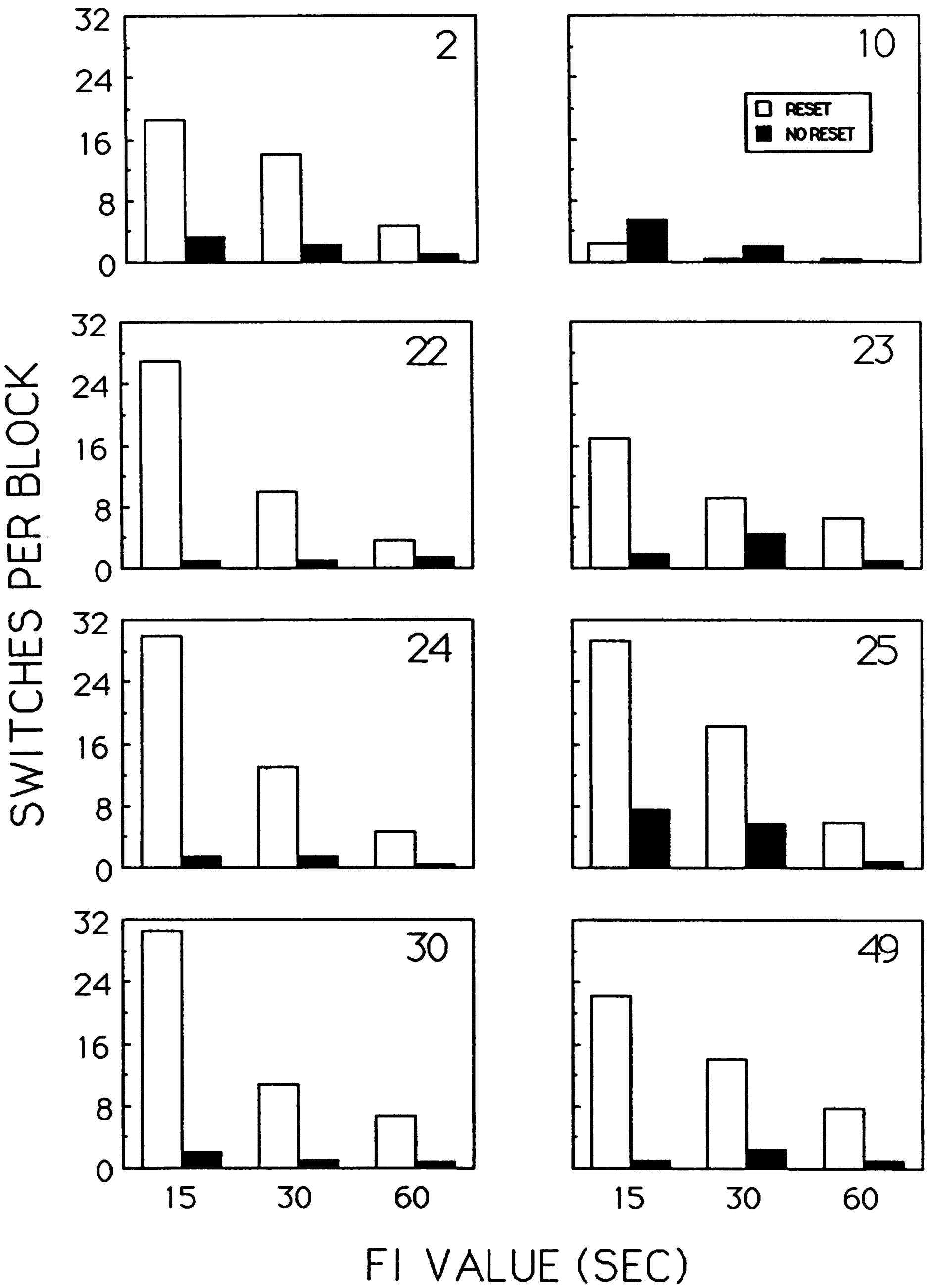

Fig. 1. Mean number of switches per block from the PI to the FI schedule under reset (open bars) and no-reset (closed bars) conditions over the final four blocks in each session for each subject.

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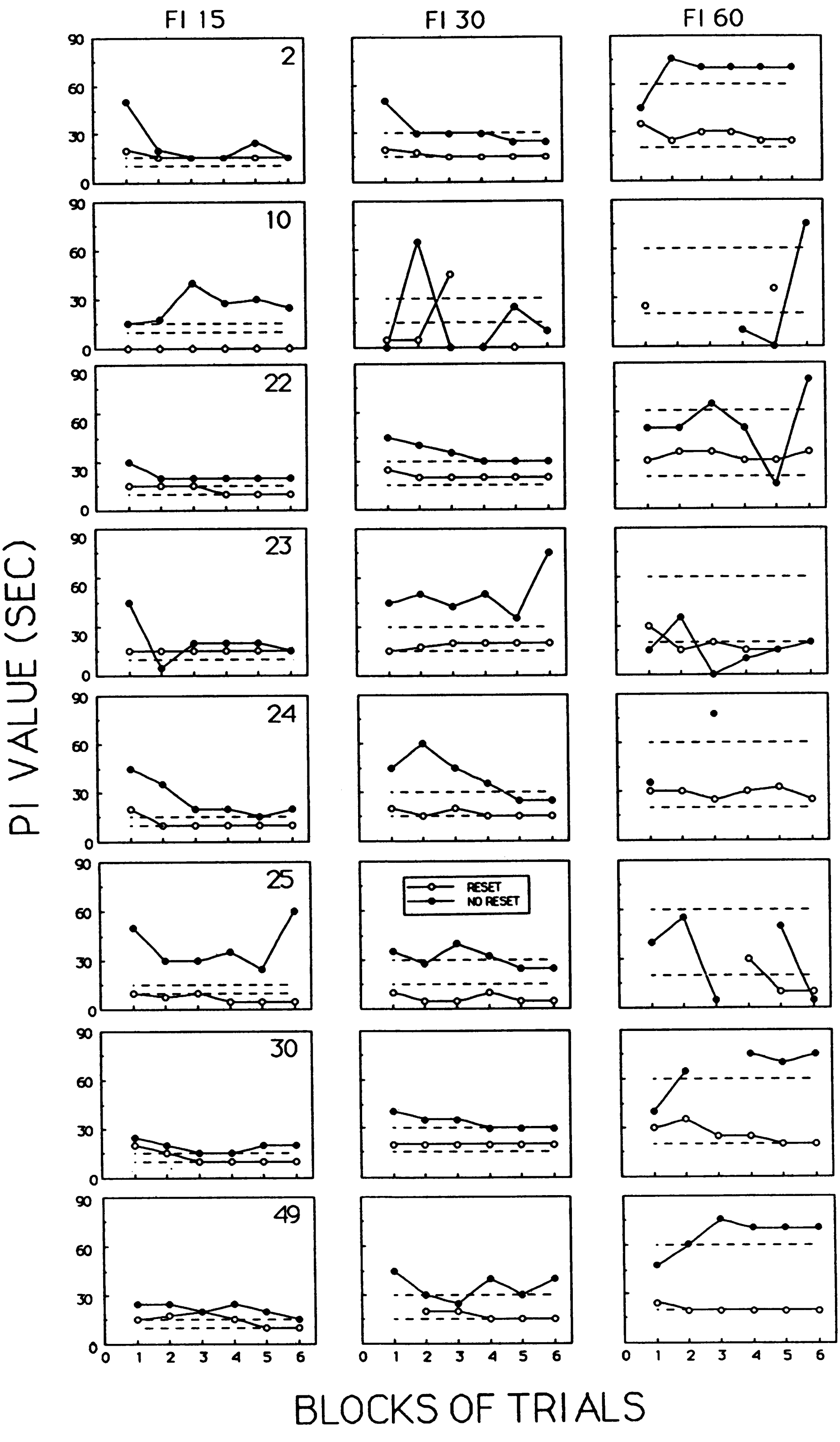
Fig. 2. Within-session median points of switching from the PI to the FI schedule under reset (open symbols) and no-reset (closed symbols) conditions across successive blocks of choice trials for each FI value. The broken lines are reference points; the upper line in each plot indicates the optimal switch point under no-reset conditions, and the lower line is the optimal point under reset conditions.


FI 15
FI 30
FI 60
2
10
22
23
24
25
30
49
RESET
NO RESET
PI VALUE (SEC)
BLOCKS OF TRIALS
0
30
60
90
0 1 2 3 4 5 6

1 presents mean number of switches per block from the PI to the FI over the final four blocks in each session. In all but Subject 10, switching occurred more frequently under reset than under no-reset conditions at each FI value, indicating sensitivity to the reset contingency. Under reset conditions, the frequency of switches per block was inversely related to FI duration, providing a rough indication of sensitivity to the size of the FI schedule.

A more direct measure of sensitivity to FI size is provided in Figure 2, which shows the position in the PI sequence when switching occurred. The figure presents median points of switching for each subject under reset and no-reset conditions across successive blocks of choice trials. The median in this case is the PI value above and below which one half of the FI choices occurred. Also included are reference functions, marked by broken lines; the upper line in each plot denotes the equality point at that FI value (optimal under no-reset conditions), and the lower one is the optimal switch point under reset conditions, delineating the sequence of choices that maximizes overall reinforcement rate. (There are technically two equality point functions, one at the nominal FI value, e.g., 30 s, and a second at one step exceeding that value, e.g., 35 s. The only difference is whether one of the 30-s intervals comes via the progressive or the fixed schedule. For clarity of presentation, only the nominal value is shown.) By convention, the switch points shown in this figure are based on the PI confronting the subject when the FI was chosen, rather than on the PI requirement of the preceding trial. Thus, choosing the FI on the trial immediately after completing a PI requirement of 25 s would be recorded as a switch point of 30 s, because that would be the schedule value currently opposing the FI.

Switch points in Subjects 2, 22, 30, and 49 increased as a function of FI value, indicating sensitivity to FI size. This relationship is seen most clearly in the no-reset functions. Switching in Subject 23 was also related to FI size, but only at the lower two values, which, for this subject, were experienced as the final four conditions. For the subjects whose switching patterns were controlled by FI size, median switch points were reasonably stable by the end of six blocks of trials. (Data from the first reset block under FI 30 for Subject 49 were lost due to a computer malfunction; other plots with less than six reset or no-reset points indicate blocks with no FI choices.)

Variability in switch points tended to decrease across blocks within conditions and was somewhat higher under no-reset than under reset conditions. Variability also increased with FI size, and was greatest for those subjects experiencing FI 60 first in the sequence. In 4 subjects (10, 24, 25, and 30), there was at least one block of trials under no-reset 60 in which FI choices did not occur. These were conditions in which responding clearly fell short of achieving a steady state, suggesting the need for longer exposure to the procedures.

Within blocks of trials, subjects did not switch exclusively at a single value in the PI sequence. Instead, choices were distributed across a range of values. The percentages of resetting and nonresetting FI choices at particular steps in the PI sequence are shown in Figure 3. The broken vertical lines denote optimal switch points under reset (left line in each plot) and no-reset (right line) conditions. Consistent with the median switch-point data, choice distributions tend to shift to the right with FI size, with resetting FI choices occurring consistently earlier in the PI sequence than nonresetting choices, though seldom do all of the choices occur at a single position in the sequence. Switch points under no-reset conditions often approximated or slightly exceeded the equality point; switch points under reset conditions were more closely aligned with predicted optimal points than with equality points. There were several conditions, however, in which switch points exceeded those optimal points in a manner consistent with Shull and Spear's (1987) formulation (Equation 1).

Table 2 provides a more systematic comparison of reset switch points to the predictions of optimality and to those of Shull and Spear's

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Fig. 3. Percentage of FI choices occurring at particular steps in the PI sequence under reset (open bars) and no-reset (closed bars) procedures for each FI value tested. The broken vertical lines indicate optimal switch points under no-reset (right line) and reset (left line) for each condition.

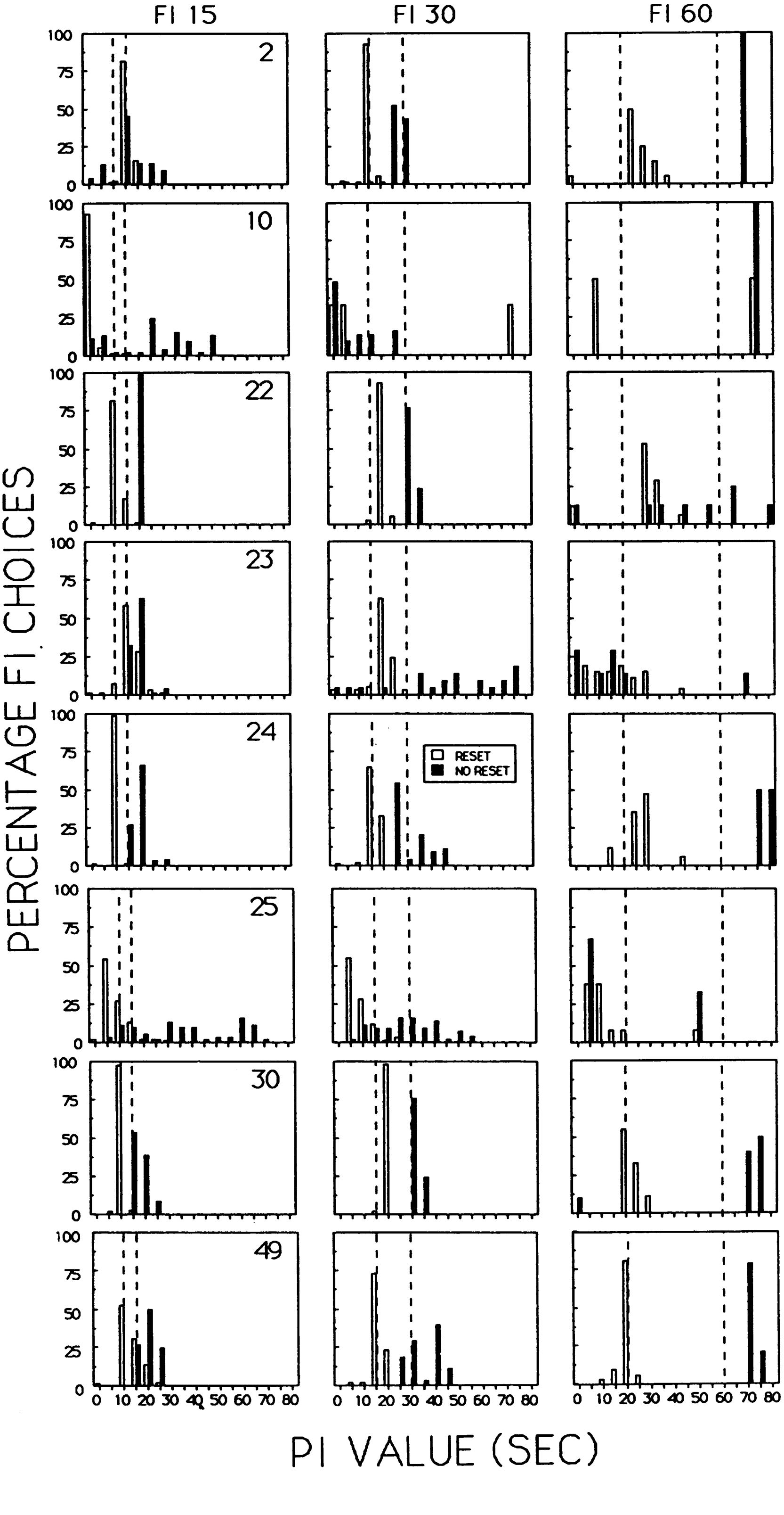

FI 15
FI 30
FI 60
2
10
22
23
24
25
30
49
RESET
NO RESET
0 25 50 75 100
0 10 20 30 40 50 60 70 80
PERCENTAGE FI CHOICES
PI VALUE (SEC)

Table 2

Signed deviations from predictions of optimality theory (opt), and from Equation 1 summed over a single reinforcer ($n = 1$) and over four reinforcers ($n = 4$) over the final four blocks of each reset condition.

	FI duration (s)								
	15			30			60		
Subject	$n = 1$	$n = 4$	opt	$n = 1$	$n = 4$	opt	$n = 1$	$n = 4$	opt
Predicted	15	10	10	30	20	15	60	35	20
2	0	+5	+5	−15	−5	0	−32.5	−7.5	+7.5
10	−15	−10	−10	−7.5	+2.5	+7.5	−25	0	+15
22	−3.8	+1.2	+1.2	−10	0	+5	−27.5	−2.5	+12.5
23	0	+5	+5	−10	0	+5	−42.5	−17.5	−2.5
24	−5	0	0	−13.8	−3.8	+1.2	−31.9	−6.9	+8.1
25	−8.8	−3.8	−3.8	−23.8	−13.8	−8.8	−43.3	−18.3	−3.3
30	−5	0	0	−10	0	+5	−37.5	−12.5	+2.5
49	−1.3	+3.7	+3.7	−13.8	−3.8	+1.2	−40	−15	0

(1987) account (see the appendix for how switch points were computed). The predicted optimal switch points are based on overall reinforcer/time ratios that would result from consistently switching at optimal, which in the current circumstances are the same as those predicted by maximization theory. Predictions of Equation 1 are summed over either one reinforcer ($n = 1$) (control of choices on a trial-by-trial basis, which on these procedures coincides with switching at the equality point) or four reinforcers ($n = 4$) (control of choice by consequences distributed over a span of four trials). This value was chosen because it has yielded a better description of the pigeon data (Hackenberg & Hineline, 1992; Wanchisen et al., 1988) than any other single aggregate size, and because it is a value beyond which the predicted switch points do not change appreciably until the equation converges on optimality.

Table 2 shows signed deviations (obtained median switch points minus predicted switch points) across the final four blocks in each condition. On the whole, optimality and Equation 1 aggregated over four reinforcers provide a better description of the data than when the equation is summed over only a single reinforcer. The two more molar predictions coincide at FI 15 s, and do about equally well in accounting for switch points at FI 30 s. Of the 6 subjects for whom stable patterns of reset choices are evident at FI 60 s, 3 subjects' switch points (Subjects 23, 30, and 49) are in closer agreement with optimality, 2 (Subjects 22 and 24) with Equation 1, with 1 (Subject 2) falling directly in between.

Schedule-Controlled Patterns

In addition to choices, response patterns in the presence of the chosen schedules (i.e., space-bar responses) are also of interest. Because schedule requirements could be satisfied either by continuous or discrete responses, both holding and pressing of the space bar appeared as topographies in our subjects. Although this rendered analyses of discrete presses difficult, schedule control is discernible by examining relations between postchoice pausing and interval requirements. The pausing of concern here is the time between the selection of a schedule and the initiation of space-bar responding on that schedule. Figure 4 shows mean pausing between FI choices and FI space-bar responses computed over the final four blocks of each session. In the 5 subjects whose choices were most clearly related to the contingencies (Subjects 2, 22, 24, 30, and 49), temporal control by the chosen schedules was also usually present. Pausing increased with FI duration on the no-reset procedure for Subject 49 and on both procedures for Subjects 2, 22, 24, and 30.

In 4 of these same 5 subjects (2, 24, 30, and 49), PI pausing also showed some degree of sensitivity to the escalating requirements of the PI schedule. Figure 5 shows mean pausing prior to PI space-bar responding across successive steps in the PI sequence over the final four blocks of each session. Control by PI re-

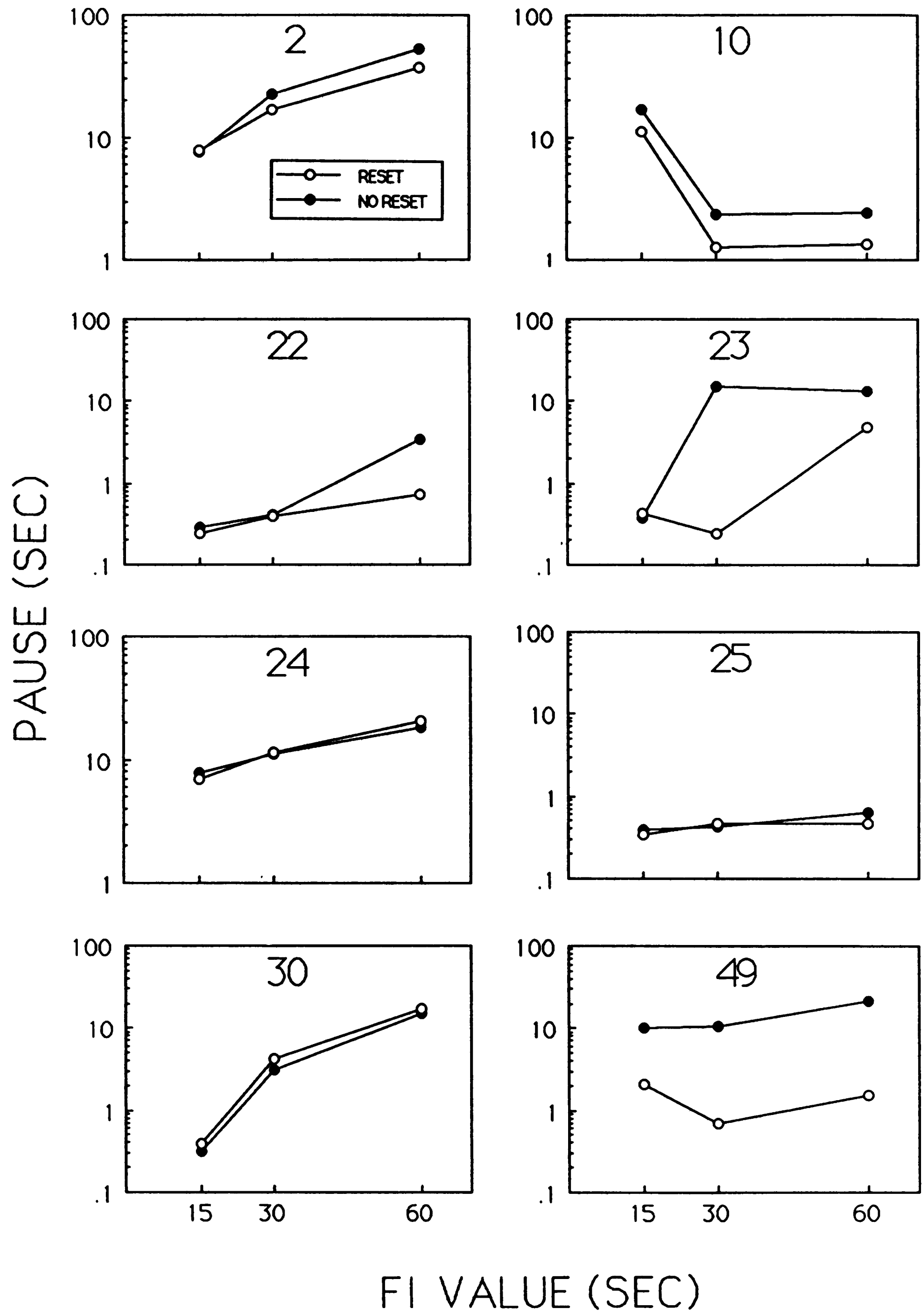


Fig. 4. Mean postchoice pause under resetting (open symbols) and nonresetting (closed symbols) FI schedules, computed over the final four blocks of choice trials in each session. Note individually scaled logarithmic axes.

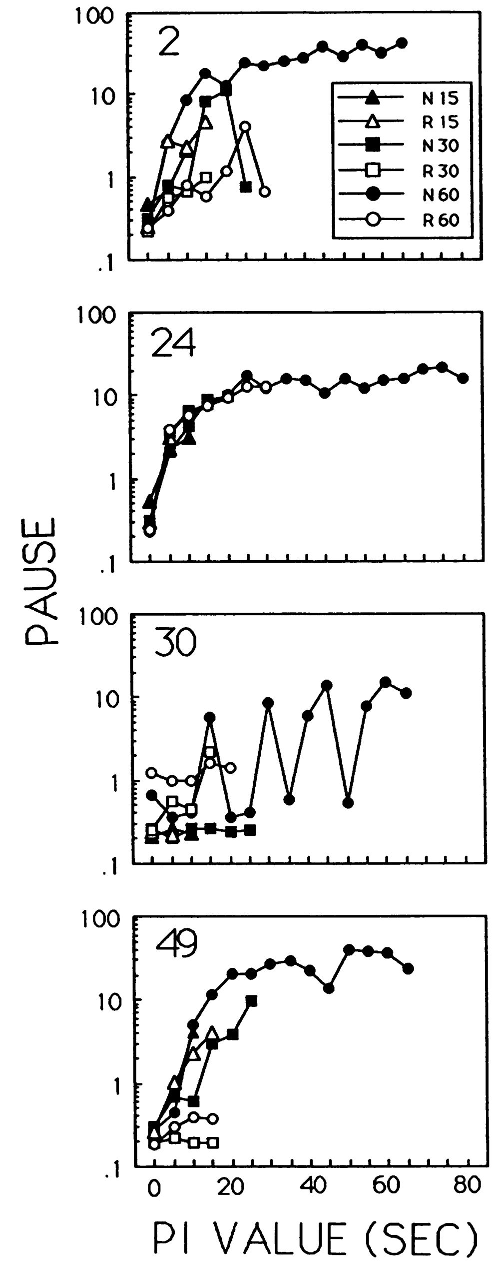


Fig. 5. Mean postchoice pausing under the PI schedule as a function of current position in the PI sequence across the final four blocks of choice trials in each session. R and N refer to reset and no-reset conditions, respectively; the number immediately following those labels denotes FI value in seconds. Note logarithmic axes.

quirements is more evident under no-reset than under reset conditions, despite limited (once per block) exposure to each step in the PI sequence in these conditions. There was little or no control by PI requirements in the remaining 4 subjects, whose data are not shown in the figure.

Verbal–Nonverbal Relations

To assess relations between verbal and nonverbal behavior, subjects' responses to within-sessions queries were analyzed in relation to switching patterns. The verbal responses were first sorted independently by two raters into two nonoverlapping categories—those which specified an actual sequence of choices (e.g., "pick four blues, then switch to red"), and those which did not (e.g., "get as many points as possible"). Raters were then instructed to score responses from the former category (i.e., those specifying a sequence) according to the number of blue (PI) choices prior to a red (FI) choice. For example, the verbal reports, "blue, blue, blue, red," and "choose six blues before red," would be assigned scores of 3 and 6, respectively. (To facilitate agreement between raters, a preliminary training session was conducted, in which both raters scored approximately 40 verbal reports from a related study. Any disagreements were resolved at this time by a mediator familiar with the research.) Interrater agreement (agreements divided by agreements plus disagreements) was 92% for the initial sorting task and 90% for the scoring task. Once scored, the verbal reports were ranked according to their deviation from the optimal sequence for that condition. For example, verbal-report scores that corresponded to the optimal pattern were assigned a ranking of 0, those one step from optimal were assigned a ranking of 1, and so on. These ranked deviations were then analyzed in relation to nonverbal switch points (computed similarly) across blocks of trials. In this way, temporal relations between verbal and nonverbal behavior were potentially discernible. The temporal resolution of this type of analysis is admittedly low; it does, however, provide at least a coarse measure of verbal–nonverbal relations.

In the 5 subjects whose choices were systematically related to the contingencies, relations between verbal and nonverbal patterns were also sometimes evident. Figure 6 shows illustrative plots representing several distinct verbal–nonverbal patterns that were evident across these 5 subjects, who made a total of 25 verbal reports that specified actual se-

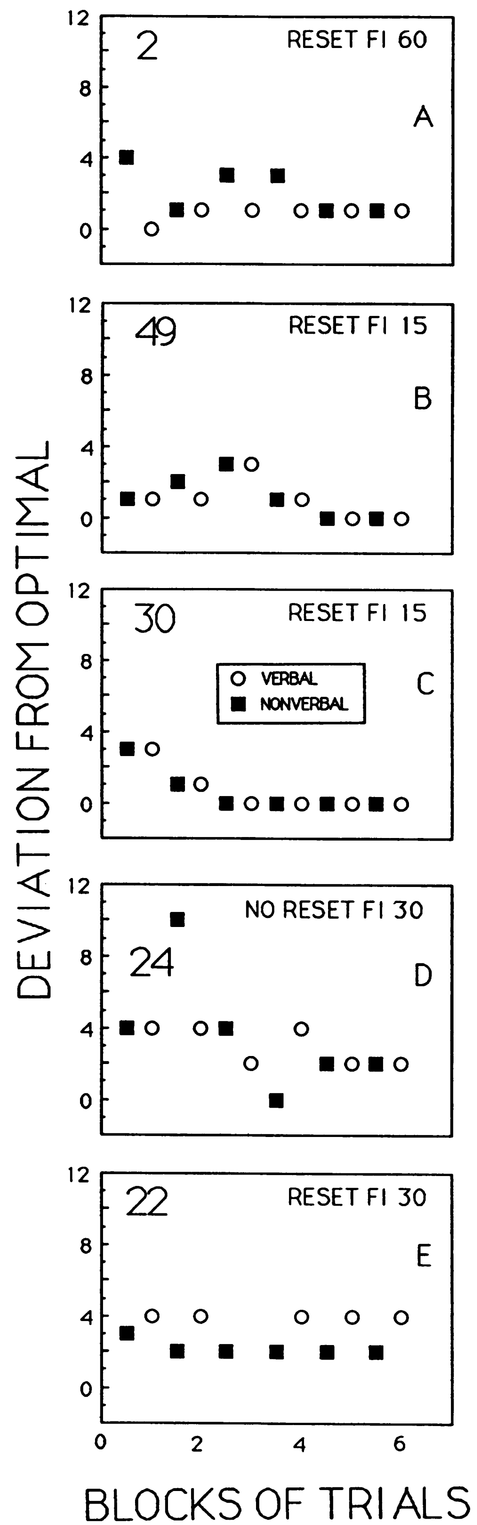


Fig. 6. Verbal reports (open circles) and median switch points (filled squares), each expressed as deviations from optimal, across successive blocks of choice trials in a session. Each plot represents a distinct verbal–nonverbal relationship. The verbal report following the third block in Panel E (Subject 22) failed to specify an actual sequence of choices. See text for other details.

quences of choices. (Verbal reports of the remaining 3 subjects failed to identify actual sequences and thus are not included in the analysis.) In five of six conditions for Subject 2, optimal or nearly optimal verbal patterns preceded corresponding choice patterns (see Panel A in Figure 6 for one such condition). In 10 of the remaining 19 cases for the other 4 subjects, however, changes of verbal report lagged behind nonverbal changes (Panel B); accurate descriptions of the contingencies were obtained under some conditions, but sometimes only after nonverbal patterns had already come under control of those contingencies (Panel C). In another four cases, changes of verbal report both preceded and followed changes in switching patterns within a session (Panel D). In the remaining four cases, verbal reports and nonverbal switching patterns, although both orderly and stable, were not related in any straightforward way (Panel E).

EXPERIMENT 2

Choice patterns in Experiment 1, when stable, were systematically related to FI size and, under reset conditions, to reinforcement variables extending beyond the current trial. Choices were generally more sensitive to reinforcement variables in subjects for whom space-bar responding also showed some sensitivity to the schedule once it had been chosen. This finding parallels the results of a recent study by Silberberg, Thomas, and Berendzen (1991), in which humans' choices under concurrent variable-interval variable-ratio schedules were more sensitive to overall reinforcement rates when schedule-appropriate responding had been separately established under each schedule. On the other hand, in standard concurrent-chains procedures, which are closer to those used here, choices of schedules appear to be independent of responding in the presence of those schedules (Autor, 1969; Herrnstein, 1964; see also Schuster & Rachlin, 1968, for analogous effects with punishment). These latter results suggest that choices be-

Table 3

Sequence of conditions for each subject in Experiment 2. "R" and "N" refer to reset and no-reset conditions, respectively.

Session	Subject 39	42	50	59
1	N FT-PT	N FI-PI	R FI-PI	R FT-PT
2	R FT-PT	R FI-PI	N FI-PI	N FT-PT
3	N FI-PI	N FT-PT	R FT-PT	R FI-PI
4	R FI-PI	R FT-PT	N FT-PT	N FI-PI
5	N FT-PT	N FI-PI	R FI-PI	R FT-PT
6	R FT-PT	R FI-PI	N FI-PI	N FT-PT

tween schedules are related directly to the reinforcement they provide rather than to the response requirements they entail.

In Experiment 2 we examined the effects of such response requirements in the presence of the chosen schedules on choices between those schedules. Choices were studied under response-dependent and response-independent schedules of point delivery of equal value. If choice patterns depend on sensitivity to the requirements of the chosen schedules, then one would expect choices to vary as a function of presence or absence of schedule requirements following choices. Conversely, if choices are related directly to patterns of delayed point deliveries, irrespective of intervening response contingencies, then one would expect choice patterns to be roughly equivalent under both types of scheduling arrangements.

An additional reason for studying choices with and without response requirements was that some of the subjects in Experiment 1 appeared to engage in collateral counting and timing responses, for which differential response patterns in the presence of the chosen schedules may have served a discriminative function. Some of the verbal reports suggested that response patterns may have aided subjects' timing of intervals by providing a temporal marker of trial duration. Removing the basis for response patterns occasioned by the chosen schedules will possibly reveal the participation of such patterns in collateral verbal behavior.

METHOD

Subjects and Apparatus

Four female adult volunteers between the ages of 19 and 25 participated in exchange for money. As in Experiment 1, subjects were recruited by fliers posted on the University of Minnesota campus. Three subjects (39, 42, and 59) were concurrently enrolled in a general psychology course and received course credit for their initial training session. Subject 50 was paid $8.00 for her initial training session. All conditions of participation and payment were as those in Experiment 1. The apparatus and stimuli were also the same as in Experiment 1.

Procedure

Performances under schedules of response-dependent versus response-independent point delivery were compared. In response-dependent conditions, subjects chose between FI 30-s schedules and PI schedules with a 5-s step size. In response-independent conditions, subjects chose between fixed-time 30-s (FT 30-s) schedules and progressive-time (PT) schedules with a 5-s step size. In the latter two schedules, points were delivered irrespective of responding at the programmed interval values. For example, choosing the PT at 25 s produced a point after a 25-s delay, regardless of what the subject was doing at the time or had done since the choice was made. As in the first experiment, immediately following each 12-min block of choice trials, subjects were asked to enter verbal reports concerning the best way to earn points. A session consisted of six 12-min blocks, with a 1-min break between blocks.

As shown in Table 3, each subject was exposed to reset and no-reset procedures under both response-dependent and response-independent scheduling of point delivery, with the sequence of both manipulations counterbalanced across subjects. Each condition lasted one session (six blocks), and a subject's first two conditions were replicated in Sessions 5 and 6. The written instructions of Experiment 1 were used, except that the line stating: "To earn points, use the space bar" was changed to: "To earn points, you will sometimes need to use the space bar." All other details were as in Experiment 1.

RESULTS AND DISCUSSION

Switching Patterns

Across subjects and conditions, reset and no-reset switching patterns were clearly distinct, regardless of the way point deliveries were scheduled (see Figures 7 and 8). Figure 7 shows mean switches per block over the final four blocks in each session. Figure 8 shows median switch points from the progressive to the fixed

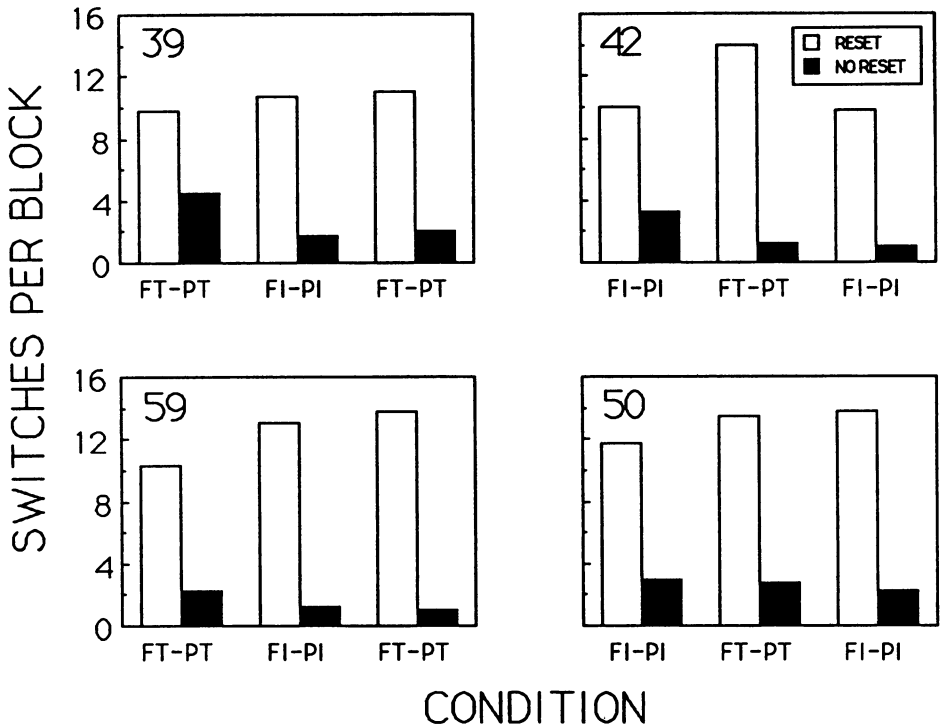


Fig. 7. Mean number of switches per block from the progressive to the fixed schedule under reset (open bars) and no-reset (closed bars) conditions over the final four blocks in each session for each subject.

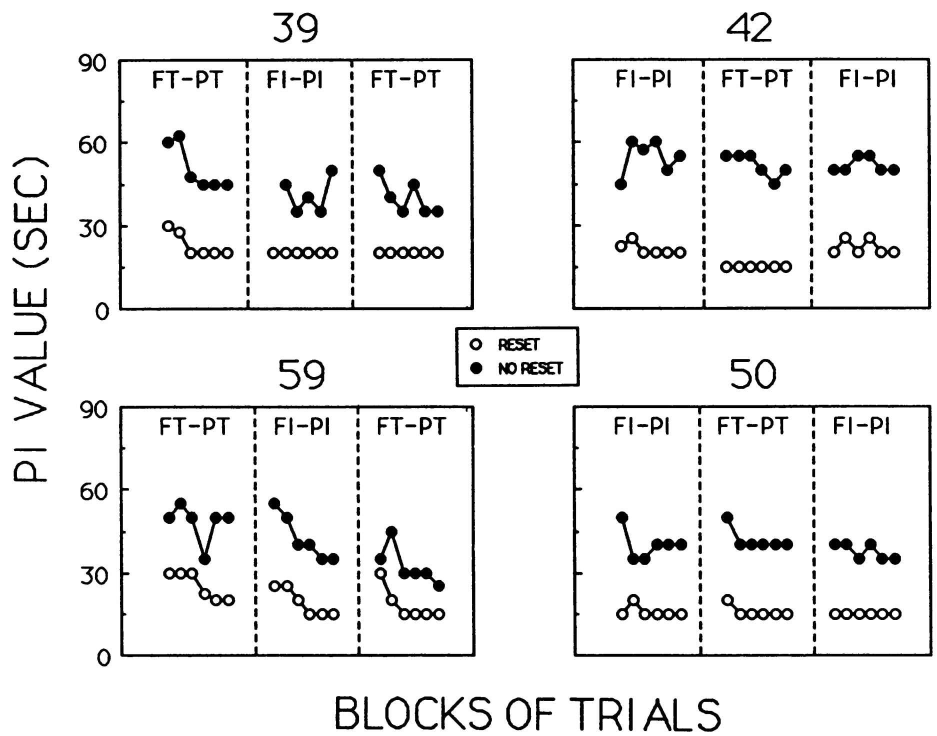


Fig. 8. Median points of switching from the progressive schedule (PI or PT) to the resetting (open circles) and nonresetting (closed circles) fixed schedule (FI or FT) across successive blocks of choice trials per condition.

schedule across successive blocks of choice trials in each session. Switching occurred both more frequently (Figure 7) and earlier in the progressive-schedule sequence (Figure 8) under reset than under no-reset conditions. In some subjects performance improved over time, but there were no systematic differences between the response-dependent (FI-PI) and response-independent (FT-PT) procedures.

In the reset conditions, median switch points in Subject 50 were in closer accord with the predictions of optimality theory, which predicts switching at a PI (or PT) value of 15 s, whereas those of Subject 39 were in closer agreement with Equation 1 summed over four reinforcers, which predicts switching at a PI (or PT) value of 20 s. Switching patterns of Subject 42 favored Equation 1 in two conditions and optimality in one, and those of Subject 59 favored optimality in two conditions and Equation 1 in one.

The distributions of fixed-schedule choices across successive steps in the PI sequence are presented in Figure 9. Each bar represents the percentage of FI choices occurring at a given step in the PI sequence, pooled across the final four blocks of trials in each condition. Data from replicated conditions were averaged with those from first exposures. Although choices were dispersed over a range of PI values under both procedures, reset choices occurred consistently earlier in the PI sequence than no-reset choices under both response-independent and response-dependent conditions. Thus, consistent with the summary measures shown in Figures 7 and 8, choice patterns were sensitive to the reset contingency, but were not sensitive to the difference between response-dependent and response-independent schedules.

Schedule-Controlled Patterns

Temporal control by the PI and FI schedules was assessed by examining pausing prior to the initiation of space-bar responding under response-dependent conditions (space-bar responses were virtually absent under response-independent conditions). Figure 10 presents, for each subject, pausing after PI choices across successive steps in the PI sequence. (Data from replicated conditions for Subjects 42 and 50 are connected by broken lines.) Pausing increased as a function of interval size in Subject 59 under the reset procedure and in Subjects 39 and 50 under both procedures, indicating sensitivity to the temporal requirements of the PI schedule. In these seven conditions in which PI temporal control was evident, FI pausing was within the range of pausing observed in the schedule-sensitive subjects under the FI 30-s conditions in Experiment 1 (see Figure 4). Pausing in Subject 50 was particularly sensitive to the FI requirements; mean pause time, collapsed across replications, for this subject was 29.6 s and 28.0 s under no-reset and reset conditions, respectively. Pausing in Subject 42 was virtually insensitive to the interval requirements of either schedule, despite orderly patterns of choices between those schedules.

Verbal–Nonverbal Relations

Verbal reports were sorted and scored independently by two raters, as described above. Agreement between raters was 95% and 85% for the sorting and scoring tasks, respectively. In 16 of 18 conditions for Subjects 39, 50, and 59, verbal reports specified actual sequences of choices, but the relationship between those verbal reports and nonverbal choice patterns varied within and between subjects (see Figure 11 for representative plots). In 3 of 18 cases, changes in verbal patterns preceded corresponding changes in nonverbal patterns (Panel A of Figure 11); in five cases, verbal changes followed nonverbal changes (Panel B); in three cases, verbal changes coincided with nonverbal changes (Panel C); in two cases, verbal changes both preceded and followed nonverbal changes across blocks of trials in a single session (Panel D); and in three cases, verbal changes were unrelated to nonverbal changes (Panel E). For Subject 42, too few verbal reports of the type that specified sequences were collected to permit any conclusions regarding verbal–nonverbal relations.

In sum, consistent with the results of Experiment 1, switching occurred earlier in the progressive-schedule sequence under reset than under no-reset conditions, demonstrating sensitivity to remote consequences. These switching patterns, however, did not depend on whether the production of points was response dependent or response independent. This shows that choices were related directly to patterns of delayed point delivery, independent of response requirements (or response patterns) in

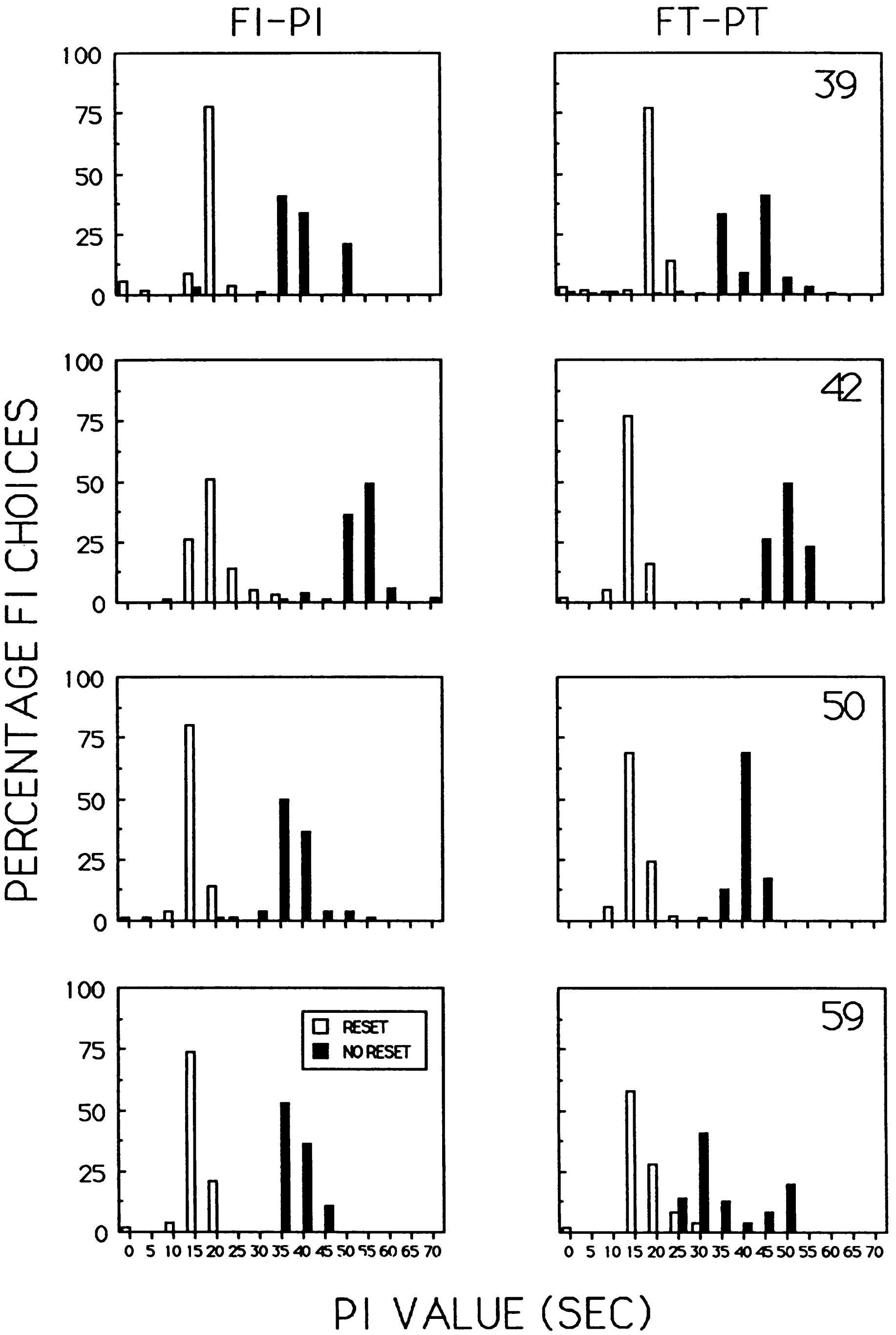


Fig. 9. Percentage of resetting (open bars) and nonresetting (closed bars) fixed-schedule (FI or FT) choices occurring at each progressive schedule (PI or PT) value. Data were pooled across replicated conditions within subjects.

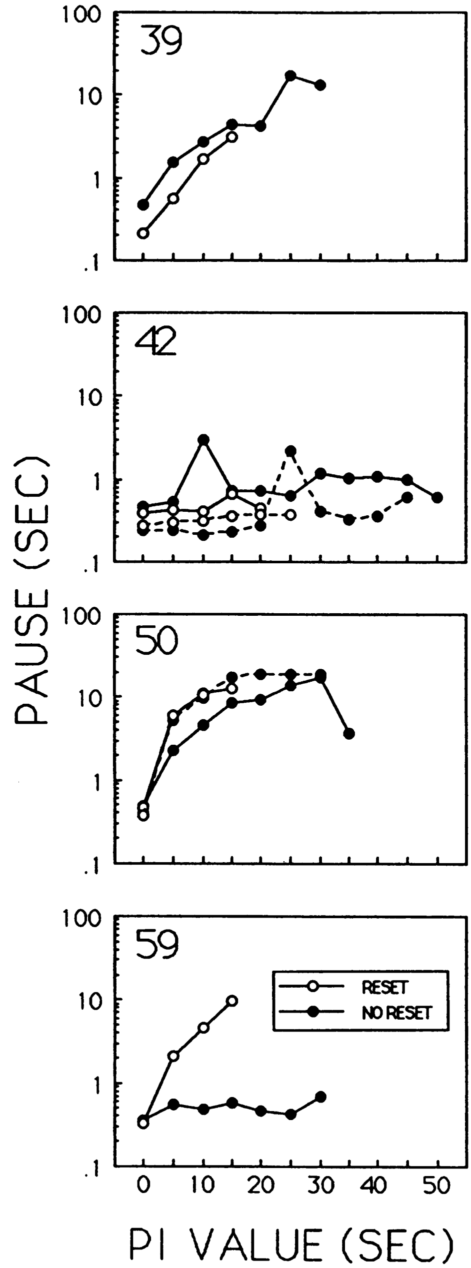


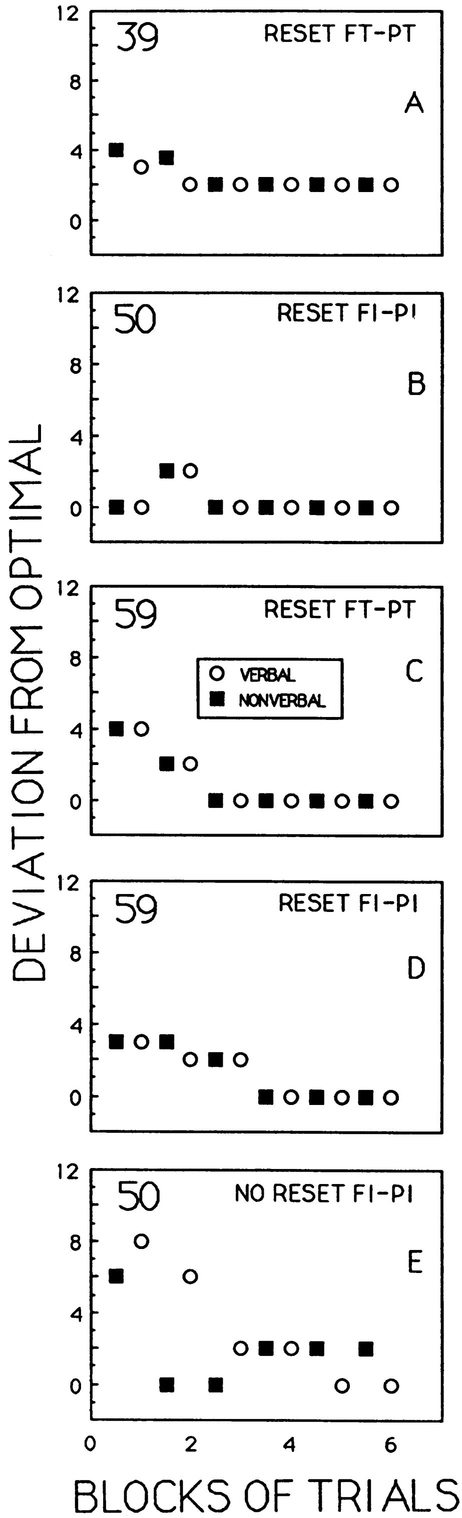
Fig. 10. Mean postchoice pause under the PI schedule as a function of PI value in reset (open symbols) and no-reset (closed symbols) procedures, computed over the final four blocks in each session. Data from replicated conditions are connected with broken lines. Note logarithmic axes.

the presence of the chosen schedules. The possibility remains open that subjects engaged in collateral timing or counting, but the results of this experiment indicate that schedule-controlled response patterns were not among the discriminative events controlling such collateral behavior. Temporal control by the FI and PI schedules was virtually absent in Subject 42, as were task-relevant verbal reports, yet her choices were systematically related to the contingencies.

EXPERIMENT 3

The results of the first two experiments are consistent with the proposition that humans' choices are sensitive to temporally distant consequences. The results, however, do not offer unequivocal support to either the predictions of optimality theory or Shull and Spear's (1987) delay-based formulation. Although the approaches make distinct predictions in some of the present conditions, the data do not consistently favor either interpretation. Of the 28 conditions in both experiments in which stable choice patterns were achieved and for which the two models predict different switch points, the results of 13 favor optimality, 12 favor Equation 1 summed over four reinforcers, and 3 favor Equation 1 summed over one reinforcer.

A more direct method for distinguishing between the predictions of these two accounts was suggested by Mazur and Vaughan (1987). In their experiment, pigeons were given repeated choices between an FR 81 and a PR schedule that began at one response and increased by 10 responses with each food delivery provided by that schedule. As in the reset conditions in the present study, choosing the fixed schedule reset the progressive one to its minimum value. Some conditions included an intertrial interval (ITI) between food deliveries and subsequent choice trials. Mazur and Vaughan showed that adding this constant time period between choices changed neither the ratio of responses per reinforcer or time per reinforcer. The optimal point of switching is the same with or without an ITI; thus, a literal application of optimization principles would lead one to expect no relationship between choice patterns and ITI. Likewise, at the other extreme, if choices are sensitive only to consequences on the upcoming trial (Equation 1 summed over a single reinforcer), then choices will be unaffected by events between trials. However, if choices are related to delayed consequences in a manner consistent with Equa-



tion 1 aggregated over several trials, then choices will vary as a function of the ITI manipulation. Because reinforcer delays are all timed from a single choice point, adding an ITI between successive choice phases increases the delay between a choice and remote reinforcers in the series. The net effect of the ITI, then, is a reduction in the reinforcing effectiveness of that particular series of reinforcers, which should enhance control by more proximal reinforcement variables. As a result, Shull and Spear's (1987) model predicts greater persistence on the progressive schedule (i.e., switching closer to the equality point) with increasing ITI values.

In Experiment 3, humans were exposed to choices between FT and PT schedules of point delivery. To assess the differential predictions of the delay-based model of Equation 1 and optimization accounts, conditions were run with and without an ITI between point deliveries and subsequent choices. Response-independent schedules were used because they eliminate discrepancies between programmed and obtained delays to reinforcement, and thus provide a more straightforward evaluation of the competing interpretive accounts. The results of the previous experiment, however, suggest similar results would be obtained under response-dependent schedules. In addition, subjects received longer exposure to the procedures than in the previous two experiments; this resulted in better steady-state control.

METHOD

Subjects

Three female and 2 male adult volunteers, between the ages of 20 and 27, participated in exchange for money. Data from one of the female subjects, terminated from the study after eight sessions for vandalizing the work space, are not included in the analysis. Subjects were recruited through classified ads in a local newspaper circulated widely on the University of Florida campus. None of the subjects had specific course work in behavior analysis or learning theory.

Fig. 11. Verbal reports (open circles) and median switch points (filled squares), each expressed as deviations from optimal, across successive blocks of choice trials in a session.

Table 4

Sequence of conditions for each subject in Experiment 3. Numbers refer to ITI duration in seconds; number of sessions is given in parentheses.

Condition	Subject			
	101	102	103	105
1	0 (2)	0 (2)	50 (3)	50 (3)
2	25 (2)	25 (2)	25 (1)	25 (3)
3	50 (2)	50 (2)	0 (1)	0 (3)
4	25 (3)	25 (2)	25 (2)	25 (3)
5	0 (1)	0 (3)	50 (3)	0 (3)
6	50 (2)	50 (1)	0 (2)	50 (4)

Apparatus and Stimuli

Subjects worked in a closed experimental cubicle (2.2 m high by 1.2 m long by 1.2 m deep), and were seated in front of a computer monitor and keyboard. A ceiling-mounted fan provided ventilation and masked extraneous sound. Other apparatus and stimuli were similar to those used in the first two experiments.

Procedure

Subjects were exposed to an FT 30-s schedule and a PT schedule that began at 0 s and increased in 5-s steps with each point delivered by that schedule. Each choice of the FT schedule produced a point after 30 s and reset the PT to its minimum. As before, the inside of the blue square flashed when the PT requirements were at their minimum value. Some sessions were conducted with, and some sessions were conducted without, an ITI separating successive choice trials. In sessions with an ITI, the screen darkened after each point delivery for 25 s or 50 s, depending on the condition. In sessions without an ITI, choice phases were reinstated immediately following the point delivery that ended the preceding trial.

Sessions consisted of five 15-min blocks of trials, each separated by 1-min rest periods. As in the earlier experiments, the following message appeared on the screen between each block and the rest period: "The best way to earn points is to . . . ." A keyboard training exercise (like that described above) preceded each subject's initial session.

Subjects usually participated every weekday at approximately the same time each day. Table 4 shows the sequence of conditions for each subject and the numbers of sessions conducted under each. Subjects 101 and 102 underwent an ascending, followed by a descending, sequence of ITI durations, whereas subjects 103 and 105 experienced the opposite sequence. Careful records were kept of each subject's earnings, which were redeemable sometime after their final session of participation. To encourage full participation, subjects received $1.50 per session in bonus earnings if they remained for the duration of the experiment. For subjects completing the experiment, overall earnings (including bonus earnings) ranged from $7.24 per hour to $8.87 per hour (median = $7.68 per hour).

Conditions were changed on an individual basis when the following stability criteria were met: (a) Median switch points from the PT to the FT schedule occurred at the same PT value over the final three blocks of a session, and (b) variability in overall distribution of FT choices did not extend systematically in either direction from the median. For subject 105, whose responses were generally more variable, the former criterion was modified to include switching within ±1 step in the PT sequence. For the other subjects, the stability criteria were always achieved within three sessions.

Instructions. Instructions were mounted on the wall directly above the monitor during the entire study. These instructions, read aloud to each subject prior to their initial block of choice trials, were similar to the previous experiments but reflected the following two changes of procedure: (a) A session consisted of five 15-min blocks of trials rather than six 12-min blocks, and (b) each point was exchangeable for 6 cents rather than 4 cents. The latter change was made to bring overall earnings in line with those from the first two experiments.

RESULTS AND DISCUSSION

Figure 12 shows each subject's switching patterns across ITI duration, along with the predictions of optimization and Equation 1 summed over either one reinforcer or four reinforcers. Only the latter predicts changes in switch points as a function of ITI. Each point is the mean of median switch points taken from the final three blocks of trials in each condition. Data from replicated conditions correspond well to those from first exposures, in three cases collapsing onto a single function. For

Subjects 102 and 103, the function relating switch points to ITI duration was perfectly flat across the range of ITIs tested. For Subjects 101 and 105, switch points were nearly identical at the lower ITI durations, but decreased approximately one step under the 50-s ITI. This shift, however, was in the direction opposite that predicted by Equation 1. When more than one reinforcer is considered in the equation, switch points should increase (converge on the equality point) with ITI value, because the concatenated delays that define reinforcing effectiveness of that series of reinforcers include time between trials. The general lack of variation in switch points across the ITI manipulation favors a view based on arithmetic averaging of reinforcement, with the absolute values of those switch points conforming closely to optimal.

Relative frequencies of FT choices across PT value are shown in Figure 13. Each panel contains distributions of choices under all three ITI durations for individual subjects. For Subjects 102 and 103, there were no systematic differences between the distributions of choices under different ITI durations. For Subjects 101 and 105, the distribution of choices under the 50-s ITI condition was displaced slightly to the left of the other distributions, which follows from the median switch-point data in Figure 12. For these 2 subjects, choices were also dispersed over a wider range of PT values than for subjects 102 and 103.

To assess relations between verbal and nonverbal patterns, subjects' verbal reports were sorted and scored independently by two raters, as described above. Agreement between raters was 96% for the sorting task and 90% for the scoring task. For Subjects 101 and 102, verbal reports usually corresponded with actual choice sequences, but they nearly always lagged behind systematic changes in nonverbal behavior. For Subject 103, verbal reports infrequently specified actual sequences; when they did, however, they were in close correspondence with nonverbal switch points. Moreover, at each ITI duration for this subject, the initial verbal report in a given condition occurred on the first opportunity following systematic control of nonverbal behavior. The temporal sequence of verbal and nonverbal changes therefore is unclear. For Subject 105, too few verbal reports that met the definitional criteria for

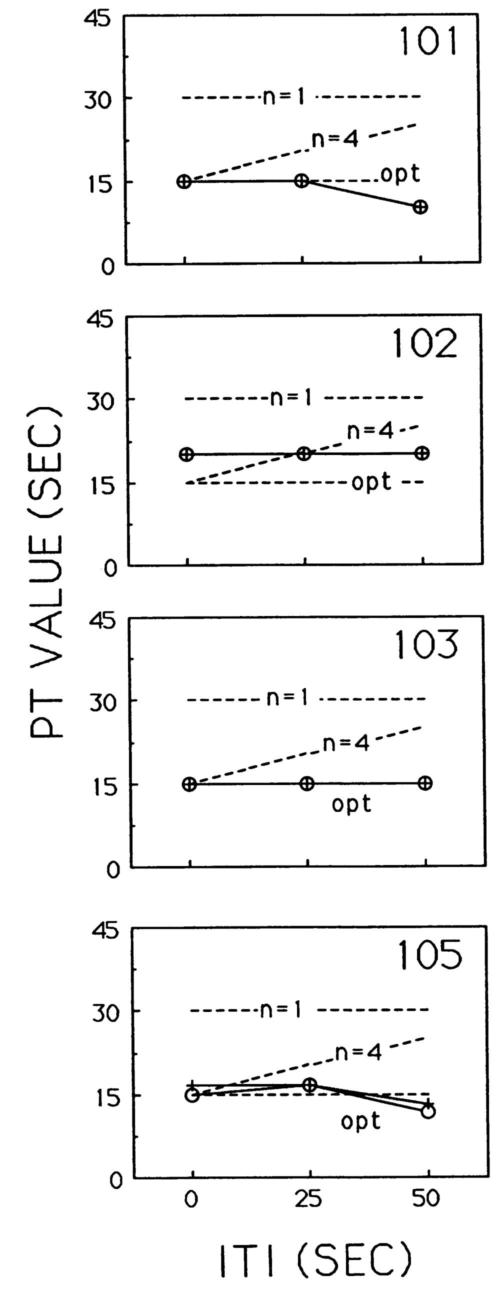


Fig. 12. Median switch points as a function of ITI duration for each subject. Circles and crosses represent data from first and second exposures, respectively. Also shown are predictions of optimization (opt) and of Shull and Spear's delay-based formulation, aggregated over one reinforcer ($n = 1$) and four reinforcers ($n = 4$).

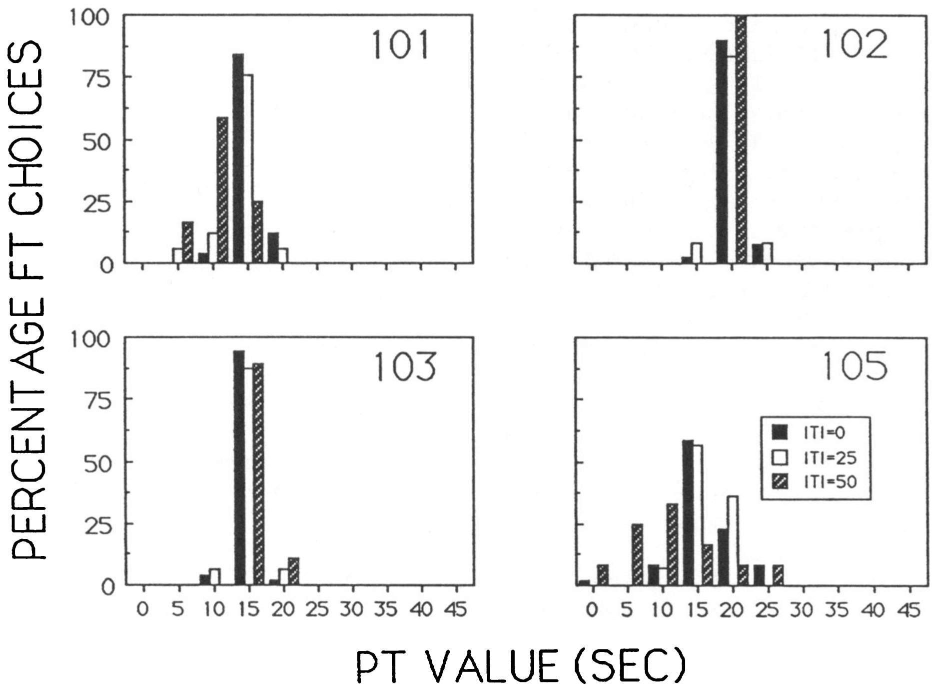


Fig. 13. Percentages of FT choices occurring at each PT value as a function of ITI duration for each subject. Data are from the second exposure to each ITI duration.

inclusion in the analyses were collected to permit any definitive conclusions regarding verbal–nonverbal relations.

GENERAL DISCUSSION

The procedures used in this study generated stable choice patterns in adult humans in a relatively short period of time. Some of the results should be viewed cautiously, because there were some conditions, particularly in Experiment 1, in which experimental control was insufficient or incomplete. Nevertheless, some general conclusions appear to be justified by the present data. In the subjects for whom stable responding was achieved in Experiment 1, points of switching from the PI to the FI increased with FI duration, demonstrating sensitivity to the size of the fixed schedule. This finding is consistent with the results of nonhuman experimentation under both ratio (Hineline & Sodetz, 1987; Hodos & Trumbule, 1967; Wanchisen et al., 1988) and interval (Hackenberg & Hineline, 1992) contingencies. When control by FI size was evident, no-reset choices approximated or slightly exceeded the equality point, this being a general pattern supported by both proximal and temporally distant consequences. Reset choices occurred well prior to that point, indicating sensitivity to consequences beyond those on the upcoming trial; this result is also in agreement with prior nonhuman work.

Differences between switching patterns under reset and no-reset conditions were replicated in Experiment 2 in choices with response-dependent and response-independent outcomes. Sensitivity to events within and between trials was shown in Experiment 3 in choices with and without an ITI. To summarize briefly the effects of both manipulations: It did not appear to matter whether responses were required in the presence of schedules once they were chosen (Experiment 2) or how far apart choices were separated (Experiment 3). The overall pattern of results is consistent with optimization models, such as Charnov's (1976) marginal value theorem, among others. At some values, the data are also in accord with Shull and Spear's (1987) delay-based account, but favor optimality when predictions of the two approaches diverge, as in Experiment 3.

The present procedures clearly dissociate short-term from long-term sources of reinforcement, and are thus relevant to issues discussed under the rubric of "self-control." Consistent with studies in that domain, humans' choices in the present study were in qualitative, and often in quantitative, agreement with optimization principles (Logue, 1988). The present procedures, however, differed from more typical methods of assessing self-control, particularly with respect to the time frame over which the terms *self-control* and *impulsivity* are applicable. In conventional choices between a small immediate reinforcer and a larger delayed reinforcer, the trade-offs between reinforcement immediacy and reinforcement amount normally occur with respect to individual choices. Although consistently choosing either of the options produces changes in both short-term and long-term reinforcement variables, the unit of responding is well specified on a trial-by-trial basis at the level of individual choices. Thus, maximizing overall reinforcement density is normally the session-wide equivalent of maximizing reinforcement density on each trial. By contrast, trade-offs between short-term and long-term reinforcement variables in the reset version of the present procedures occur with respect to sequences of choices and their correlated consequences. In Experiment 3, for example, the sequence of choices yielding the highest overall reinforcement rate under FT 30 s with 50-s ITIs consisted of three successive PT choices followed by an FT choice. Not counting latencies prior to choices, this unit includes four choices and reinforcers extending over at least 245 s. The expanded time frame made possible by these procedures may prove useful in evaluating theoretical approaches to adaptive choice, and may better approximate nonlaboratory situations in which temporal gaps between human behavior and its consequences are often extensive.

Despite differences in scale, the present data, coupled with results obtained with pigeons (Hackenberg & Hineline, 1992), are consistent with previous demonstrations of species differences in sensitivity to delayed consequences (Belke et al., 1989; Logue et al., 1986). In the Hackenberg and Hineline study, under at least the two longest FI durations per subject, pigeons' choices of a resetting FI schedule were systematically related to multiple reinforcers several trials removed in a manner consistent with Shull and Spear's (1987) account. Thus, as with the more conventional self-control procedures, there appear to be quantitatively discernible differences between humans' and pigeons' performances on the progressive-schedule choice procedures.

Such apparent species differences may be due to differences in procedure. In the present study, for example, the schedules between which the subjects chose were shorter and were varied over a narrower range than those to which pigeons have been exposed. Moreover, our human subjects received briefer overall exposure to the procedures than have nonhumans in previous research. Future work in this area should seek to minimize such procedural differences, which may be at least partially responsible for human–nonhuman discrepancies reported in the literature (see Baron, Perone, & Galizio, 1991).

Perhaps the most significant procedural difference concerns the nature of the consequences maintaining performance. In the present study, as in most experiments with human subjects, consequences consisted of generalized conditioned reinforcers (e.g., points exchangeable for money), whereas in nonhuman research consequences normally consist of unconditioned reinforcers (e.g., food or water). Unlike the latter, whose behavioral functions are established through deprivation operations, generalized conditioned reinforcers are independent of particular states of deprivation. In addition, points or money cannot be traded for consumable reinforcers until well after the end of session, so obtaining them quickly is not differentially reinforced. Together, these factors may favor a larger temporal frame of reference, enhancing sensitivity to remote outcomes. Differences between food-deprived pigeons' choices reinforced with food and nondeprived humans' choices reinforced with points or money, then, may say more about the motivational or economic context surrounding those choices than they do about species differences in temporal integration (Belke et al., 1989; Logue et al., 1986). In support of this notion, when primary reinforcers (such as food or escape from noise) serve as consequences of humans' choices, performance more closely resembles that seen in nonhumans; that is, there is greater sensitivity to reinforcement immediacy (Navarick, 1982; Ragotzy, Blakely, & Poling, 1988; Solnick, Kannenberg, Eckerman, & Waller, 1980).

Another possibility is that differences between human and nonhuman behavior center around verbal functioning. Of particular relevance to the present study are data showing that verbal behavior can modify sensitivity to programmed reinforcement variables (Catania, Matthews, & Shimoff, 1982; Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986). When behavior is instructed rather than shaped through direct interaction with its consequences, it may be less sensitive to environmental changes. Although minimal instructions were provided to subjects in the present study, it remains possible that the procedures themselves generated verbal behavior that participated in nonverbal performance.

Distinguishing verbal from nonverbal functioning has proven to be an elusive matter. When, as in the present study, explicit instructions are not provided, one typically must rely on verbal reports and their correlation with nonverbal performance. For example, Pouthas, Droit, Jacquet, and Wearden (1990) looked for parallels between verbal and nonverbal performance in mid- or postsession questionnaires as evidence of verbal regulation of nonverbal behavior. In the present study, the relationship between switching patterns and within-session verbal reports of the contingencies, though often systematic, was extremely variable both within and between subjects (see Figures 6 and 11). Verbal descriptions of the contingencies sometimes preceded, sometimes followed, sometimes coincided with, and sometimes were unrelated to changes in nonverbal behavior. This lack of a consistent relationship across subjects, and across conditions within subjects, may have resulted from our use of an open-ended response format, or to the extended, and rather coarse, contingency descriptions such a format entailed. Even with a more structured format, however, the causal status of such reports remains unclear (see Shimoff, 1986). Does verbal behavior control nonverbal behavior (Pouthas et al., 1990), is it controlled by nonverbal behavior (as in some conditions reported by Catania et al., 1982), or is it simply behavior generated by nonverbal contingencies that may or may not be necessary to satisfy those contingencies (Hineline & Wanchisen, 1989)? Although the present experiments were not designed to address these questions directly, they do illustrate a promising set of procedures for assessing species differences in sensitivity to delayed outcomes. Extending these procedures to the domain of instructional control may help to clarify relations between verbal and nonverbal functioning, and the degree to which such relations are responsible for differences between human and nonhuman action.

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APPENDIX

To illustrate the different switching patterns predicted by optimality theory and by Equation 1 summed over four choice/reinforcer cycles, consider choices under the reset FI 30-s condition. The optimal switch point, which identifies the sequence of choices yielding the highest arithmetic rate of reinforcement, was computed by dividing the number of reinforcers in the sequence by the cumulated time. Because the discrepancies between programmed and obtained delays were minimal, programmed values were used. When the PI schedule was at its minimum value, however, an 0.5-s delay was used to account for the time between the choice and the reinforced response. The following table shows, for each sequence of choices culminating in an FI choice (in boldface), the cumulative time invested, the number of reinforcers (on either schedule), seconds per reinforcer, and reinforcement rates.

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PI value	Series of choices	Σseconds	Number of reinforcers	Seconds/ reinforcer	Reinforcers/ second
0	**30**+ ···	30	1	30.0	0.033
5	0.5 + **30** + ···	30.5	2	15.25	0.066
10	0.5 + 5 + **30** + ···	35.5	3	11.83	0.084
15	0.5 + 5 + 10 + **30** + ···	45.5	4	11.37	0.088*
20	0.5 + 5 + 10 + 15 + **30** + ···	60.5	5	12.10	0.083
25	0.5 + 5 + 10 + 15 + 20 + **30** + ···	80.5	6	13.42	0.074
30	0.5 + 5 + 10 + 15 + 20 + 25 + **30** + ···	105.5	7	15.07	0.066

Recall that switch points are specified as the PI value on the trial when the FI is selected rather than on the PI value last completed. Selecting the FI exclusively (when the PI = 0) yields one reinforcer (on the FI) per 30 s; strict alternation between FI and PI yields two reinforcers (one on the PI and one on the FI) per 30.5 s, or 15.25 s per reinforcer; choosing the PI twice before switching to the FI yields three reinforcers every 35.5 s, or 11.83 s per reinforcer, and so on. Optimal performance (as indicated by an asterisk) entails switching from the PI to the FI after only three PI completions—when the PI schedule on the current trial is 15 s. The reinforcement rate produced by this sequence compares favorably to the rate that would result from switching at the equality point (PI = 30 s).

To compute the switch points predicted by Equation 1 with $n = 4$, it was necessary to compare the reinforcing effectiveness (V in Equation 1) of all 16 possible four-choice sequences at each juncture in the PI schedule. The PI value at which the sequence FI-PI-PI-PI yielded the highest V was the predicted switch point. To make explicit the predictions of Equation 1 and optimality, assume the PI schedule on the current trial is 15 s (the optimal switch point with FI = 30 s). The programmed delays to the next four reinforcers if the FI is chosen on this trial are 30 s (FI), 0.5 s (PI = 0), 5 s (PI = 5), and 10 s (PI = 10). Timing each of these reinforcer delays from the FI choice yields the following delay values (in seconds): 30 + 30.5 + 35.5 + 45.5. Taking the reciprocals and summing:

$$(1/30) + (1/30.5) + (1/35.5) + (1/45.5) \\ = 0.033 + 0.033 + 0.028 + 0.022 \\ = 0.116.$$

If, instead, the switch from the PI to the FI is made after another trial, the resulting delays (in seconds) would be 15 (PI), 30 (FI), 0.5 (PI), and 5 (PI); with reciprocals timed from the first choice:

$$(1/15) + (1/45) + (1/45.5) + (1/50.5) \\ = 0.067 + 0.022 + 0.022 + 0.020 \\ = 0.131.$$

Thus, contrary to the predictions of optimality, Equation 1 predicts choice of the PI schedule at this particular juncture. On the following trial, when the PI schedule is at 20 s, the summed reciprocals of the delays associated with persisting on the PI schedule for one more choice before switching are:

$$(1/20) + (1/50) + (1/50.5) + (1/55.5) \\ = 0.05 + 0.02 + 0.02 + 0.018 \\ = 0.108.$$

Because this value is lower than the value of the sequence beginning with an FI choice (0.116), Equation 1 predicts switching at this point in the PI sequence. It can also be shown that this value exceeds the value of persisting on the PI schedule for the next four choices:

$$(1/20) + (1/45) + (1/75) + (1/110) \\ = 0.05 + 0.022 + 0.013 + 0.009 \\ = 0.094.$$

Equation 1 therefore predicts switching from the PI to the FI when the PI equals 20 s.