INSTRUCTIONAL VERSUS SCHEDULE CONTROL OF HUMANS' CHOICES IN SITUATIONS OF DIMINISHING RETURNS

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Four adult humans chose repeatedly between a fixed-time schedule (of points later exchangeable for money) and a progressive-time schedule that began at 0 s and increased by a fixed number of seconds with each point delivered by that schedule. Each point delivered by the fixed-time schedule reset the requirements of the progressive-time schedule to its minimum value. Subjects were provided with instructions that specified a particular sequence of choices. Under the initial conditions, the instructions accurately specified the optimal choice sequence. Thus, control by instructions and optimal control by the programmed contingencies both supported the same performance. To distinguish the effects of instructions from schedule sensitivity, the correspondence between the instructed and optimal choice patterns was gradually altered across conditions by varying the step size of the progressive-time schedule while maintaining the same instructions. Step size was manipulated, typically in 1-s units, first in an ascending and then in a descending sequence of conditions. Instructions quickly established control in all 4 subjects but, by narrowing the range of choice patterns, they reduced subsequent sensitivity to schedule changes. Instructional control was maintained across the ascending sequence of progressive-time values for each subject, but eventually diminished, giving way to more schedule-appropriate patterns. The transition from instruction-appropriate to schedule-appropriate behavior was characterized by an increase in the variability of choice patterns and local increases in point density. On the descending sequence of progressive-time values, behavior appeared to be schedule sensitive, sometimes even optimally sensitive, but it did not always change systematically with the contingencies, suggesting the involvement of other factors.

Key words: instructional control, schedule control, verbal behavior, choice, progressive-time schedules, fixed-time schedules, key press, adult humans

Humans who serve as experimental subjects in psychology experiments bring to the laboratory a rich and varied history of experiences that can interact with other aspects of performance under study. An important class of experiences arises from social environments in which humans participate from an early age. As a result of longstanding involvement in social or verbal communities, humans acquire behavior not only through direct contact with naturally occurring contingencies but also through verbal descriptions of such contingencies, usually in the form of instructions, warnings, or advice from others in the surrounding community (Skinner, 1966).

By the time most people enter school, and almost certainly by the time they enter laboratory settings as experimental subjects, instruction-following repertoires are well estab-

lished. Under a wide range of circumstances, humans exhibit a standing tendency to follow instructions. Unless special precautions are taken, such instruction-following repertoires may modulate sensitivity to nonverbal aspects of performance studied in the laboratory. Although this was once seen to reflect a weakness in an operant approach to human behavior (Brewer, 1974), the direct study of relations between verbal instructions and other behavior has become a research topic of considerable interest in its own right (see reviews by Baron & Galizio, 1983, and Hayes, 1989).

It is generally agreed that behavior governed by instructions and behavior governed by direct nonverbal contact with the environment are controlled by different variables. A good deal of research in this area has therefore been devoted to teasing apart the relative influence of verbal instructions and nonverbal schedule variables in the control of human behavior. However, because behavior under instructional control can be topographically similar to behavior under direct schedule control, clear dissociations between the two response classes require studying behavior under conditions in which instructions sometimes correspond, and sometimes do not correspond, to ongoing con-

This research was supported by a Research Development Award from the University of Florida. Portions of these data were presented at the annual meeting of the Association for Behavior Analysis, San Francisco, May 1992. We are grateful to Eric Jacobs for technical and conceptual support. Correspondence and requests for reprints may be sent to Timothy D. Hackenberg, Department of Psychology, University of Florida, Gainesville, Florida 32611 (E-mail: hack@webb.psych.ufl.edu).

tingencies. When correspondence is good (i.e., when instructions accurately specify the contingencies), instructions can hasten acquisition of new behavior (Ayllon & Azrin, 1964; Baron & Kaufman, 1966). This can bring behavior into better contact with programmed contingencies, even after the instructions are removed (Hayes, Brownstein, Haas, & Greenway, 1986; LeFrancois, Chase, & Joyce, 1988). On the other hand, instruction following sometimes restricts the range of behavior available to make contact with contingencies, resulting in a marked insensitivity to changes in the environment (Baron, Kaufman, & Stauber, 1969; Catania, Shimoff, & Matthews, 1989; Galizio, 1979; Harzem, Lowe, & Bagshaw, 1978; Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986; Joyce & Chase, 1990; Shimoff, Catania, & Matthews, 1981).

A clear demonstration of the latter was provided by Galizio (1979), who found that humans' responding on an avoidance procedure was acquired rapidly and appeared to be contingency governed when the instructions and schedule requirements were in accord. When schedule conditions were changed, however, responding persisted in the previously established pattern, insensitive to the change of contingency, revealing the instructed nature of the performance in the prior condition. Thus, apparent contingency control may itself be under instructional control (so-called "pseudosensitivity," Shimoff, Matthews, & Catania, 1986); unmasking the actual controlling variables requires situations in which the correspondence between instructions and contingencies is systematically altered.

Such correspondence between instructions and contingencies is typically varied in an all-or-none fashion (e.g., by providing an instruction such as "go fast" when the programmed contingencies actually require low response rates). That is, the instructions are usually completely accurate or completely inaccurate. When degree of accuracy has been manipulated, it has typically been done across groups of subjects (Hayes, Brownstein, Haas, & Greenway, 1986; Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986). The present study was an attempt to examine in a more continuous fashion the correspondence between instructions and the contingencies specified by those instructions within individual subjects. The instructions, initially accurate, were made

gradually less so across conditions by virtue of gradual shifts in the underlying contingencies. The goals were (a) to establish and assess systematically instructional control in the face of conflicting schedule requirements, (b) to characterize the transition from instructional to schedule control, and (c) to examine the long-term effects on compliance of experience with inaccurate instructions.

The procedure was a slight variant of that used recently to study humans' choices in situations of diminishing returns (Hackenberg & Axtell, 1993). In the present experiment, subjects chose between fixed and progressively increasing delays to point delivery, arranged by fixed-time (FT) and progressive-time (PT) schedules of point delivery, respectively. Each point delivered by the PT schedule increased in fixed units the time to the next PT point. Each point delivered by the FT schedule reset the PT to its minimum value. Subjects were provided with instructions that specified a particular sequence of choices. The degree to which this instruction was accurate depended on the step size of the PT schedule, which varied systematically across conditions.

In the first experimental condition, the instruction was accurate, in that it specified the optimal pattern of choices—the pattern that would yield the highest net rate of point delivery. This definition of *optimal* requires treating entire choice sequences as integrated response units. The units of interest here concern patterns of switching from the PT to the FT schedule. The position in the PT progression at which the FT schedule is consistently selected, termed the *switch point*, provides a convenient measure of these switching patterns.

It has proven useful in these procedures to view switch points in relation to their net rate of return, from which it is possible to identify an optimal switch point. Return rates are computed here as simple arithmetic averages of the interreinforcement intervals comprising particular choice sequences. Note that a sequence is defined as a series of PT selections followed by an FT selection; this is what identifies the sequence as a switch point. To take a concrete example, consider the first condition of the present experiment, in which the FT schedule was 60 s and the PT schedule began at 0 s and increased in 4-s steps with each PT point delivery. Selecting the PT schedule just once

before switching to the FT (a pattern of strict alternation between the schedules) would yield 2 points (1 on the 0-s PT + 1 on the 60-s FT) per minute. Selecting the PT schedule twice before switching to the FT would yield 3 points (1 on the 0-s PT + 1 on the 4-s PT + 1 on the 60-s FT) per 64 s, or 2.8 points per minute, and so on. The optimal switch point under these circumstances involved selecting the PT schedule five consecutive times before switching to the FT, which would yield 6 points (5 on the PT + 1 on the FT) per 100 s, or 3.6 points per minute.

Note that this switch point is optimal only if rates of point delivery are computed arithmetically, and the time unit for computing them is taken to be an entire sequence of choices. That is, because the optimal switch point in this example requires selecting a 60-s delay to the upcoming point delivery (the value of the FT) over a 20-s delay to the upcoming point delivery (the current value of the PT after five successive choices), what is optimal at the molar level of choice sequences is decidedly non-optimal at the more molecular level of individual schedule selections and point deliveries. For the present purposes, optimal behavior is defined in the more molar sense of choice sequences. That this is a reasonable basis for evaluating performances in the present experiment is supported by the results of Hackenberg and Axtell's (1993) study, in which humans' switching patterns on similar procedures were generally in close agreement with molar optimizing (Charnov, 1976), even when such patterns frequently resulted in longer delays to points in the short run.

In the first condition of the present experiment, control by instructions and optimal control by schedule requirements both supported the same performance. In subsequent conditions, the correspondence between the optimal choice sequence and the sequence implied by the instruction was gradually altered. This was accomplished by first increasing, then decreasing, PT step size, typically in 1-s units, across conditions, while maintaining the same instructions.

This general strategy is illustrated in Figure 1, which depicts theoretical functions defined by instructed and optimally schedule-appropriate patterns across PT step size. Because the instructions were constant across conditions, the instructed switch point remained the

Fig. 1. Theoretical functions depicting instructed and optimally schedule-appropriate patterns of switching from the PT to the FT schedule across variations in PT step size. See text for additional details.

same (five PTs before an FT). As PT step size was manipulated, however, the optimal switch point occasionally changed, and, with it, the correspondence between instruction-appropriate and optimally schedule-appropriate behavior. Note that the two functions coincide at PT 4 s (the initial condition of the experiment), then diverge with increases in PT step size across an ascending sequence of conditions. In this way, relative control by instructions and contingencies could be assessed by the degree to which the switching patterns followed one function or the other as the correspondence between them was systematically altered. These procedures made it possible to examine in closer detail the interplay between instructions and contingencies and to identify points of transition from instructional to contingency control and vice versa. The long-term effects of exposure to inaccurate instructions on subsequent instructional control were also examined by reexposing subjects to conditions which had previously occasioned instruction-appropriate behavior.

METHOD

Subjects

Three men and 1 woman between the ages of 18 and 30 years participated in exchange for money. Subjects were recruited through an

advertisement in a university newspaper, and were selected in part for their lack of experience with behavior analysis, economics, and mathematics. Subjects earned \$0.03 per point in addition to a flat fee of \$1.50 per 80-min session. Overall earnings ranged from \$4.27 to \$6.29 per hour ($M = \$5.38$ per hour). No payments were made until each subject's participation was complete.

Apparatus

Sessions were conducted in a closed experimental cubicle (2.2 m high by 1.2 m long by 1.2 m deep). Subjects were seated in front of an IBM® computer keyboard and monitor. The keyboard sat on a ledge just below an opening in the wall behind which the monitor sat. The primary stimuli consisted of red and blue squares (8 cm by 8 cm) presented on the monitor screen (17 cm high by 23 cm long). Manipulanda consisted of two arrow keys on the keyboard, one pointing left ($\leftarrow$) and the other right ($\rightarrow$). A ceiling-mounted exhaust fan provided ventilation and masking noise, and a 100-W incandescent light bulb lit the work space.

Procedure

To gain familiarity with the apparatus, each subject typed a brief passage on the keyboard prior to the first session. The following instructions, mounted on the wall of the cubicle directly above the computer screen, were then read aloud to the subject:

INSTRUCTIONS: PLEASE READ CAREFULLY. To begin, press any key. To earn points, select a box using the $\leftarrow$ to select the box on the left or the $\rightarrow$ to select the box on the right. (Press only one key at a time.) Each point you earn is worth 3 cents. So, for example, if you earn 300 points, you will be paid \$9.00. The way to earn the most points is to select the blue flashing box, then select the solid blue box four consecutive times, then select the red box. Each session will last for about 15 minutes, with a 1-minute rest period between sessions. During the rest period following the third session, you may leave the room for a 5-minute break, if you so choose. At the end of each session, a message will come up on the screen asking you to record your thoughts about the experiment. When five 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.

These printed instructions remained in place in the work space for the remainder of the experiment, but were not again read aloud to the subject.

The procedure involved discrete choice points, during which the FT schedule (red square) and PT schedule (blue square) were presented side by side (4 cm apart) on an otherwise dark computer screen. The inside of the blue square flashed when the PT requirements were at their minimum value of 0 s. The left-right position of the blue and red squares was determined randomly from cycle to cycle. During this choice phase, in which both squares were available, either schedule could be selected by pressing the arrow key corresponding to the position of the schedule on the screen. For example, if the FT (red square) was on the left and the PT (blue square) on the right, pressing the $\leftarrow$ key initiated the FT schedule, whereas pressing the $\rightarrow$ key initiated the PT schedule. This choice response also disabled the alternate schedule and removed its correlated square from the screen for the remainder of that choice cycle (i.e., until a point had been delivered according to the chosen schedule). The square correlated with the chosen schedule remained on for the duration of that cycle. Point delivery, signaled by a brief audible tone and by an incrementing of a counter ("SCORE = _____") in the lower left corner of the screen, was followed immediately by the next choice cycle, indicated by the return of the red and blue squares on the screen. The delays to point delivery on both schedules were timed from the choice and were independent of any intervening responses.

A session consisted of five blocks of choice cycles, each lasting for approximately 15 min. Actual block durations varied slightly, because blocks always ended after a scheduled point delivery. (What are referred to here as "blocks" are referred to in the instructions to the subjects as "sessions.") Prior to each block of choice cycles, the following message appeared in white letters on a dark screen: "Press any key to begin." A single press on any key erased that message and initiated the first choice cycle, indicated by the red and blue squares on the screen. Following the first point delivery 15 min from the start of a block, the following message appeared near the top of the screen:

"The best way to earn points is to ____."

An empty rectangle (9 cm high by 20 cm long) was located 3 cm below this query, within which the subject's verbal response appeared as it was typed. Outside this rectangle, centered near the bottom of the screen the following prompt appeared: "Press the F2 key when finished." A single press of the F2 key during this period initiated a 1-min rest period, followed either by (a) another block of choice cycles, if the previous block was among the first four of that session, or (b) the end of the session, if the previous block was the fifth of that session. In the latter case, the following message appeared on the screen: "The session is over. You may leave now."

The requirements of the PT schedule began each block at 0 s (the choice response produced a point), but increased by a fixed number of seconds with each point delivered by that schedule. The step size of the PT schedule remained constant within conditions, but varied gradually (typically in 1-s units) across conditions. The requirements of the FT schedule were constant throughout the experiment at 60 s; that is, each choice of the FT schedule produced a point 60 s later. Each point delivered by the FT schedule also reset the requirements of the PT schedule to 0 s. Each subject was studied under many PT step sizes, beginning with 4 s (PT 4). Under these conditions, each point delivered by the PT schedule increased the delay to subsequent PT points by 4 s. Thus, the first PT choice of a block produced a point immediately, the second PT choice produced a point after 4 s, the third PT choice produced a point after 8 s, and so on, until that block of cycles ended or until an FT choice occurred. Under these circumstances, choosing the PT schedule five consecutive times before switching to the FT schedule (i.e., when the PT schedule on the upcoming cycle was 20 s) was optimal, as defined above. This pattern corresponded to that specified by the instructions mounted on the wall above the monitor (see above). In this first condition, the instructions were thus in accord with the optimal pattern of responding. As the PT step size was varied across conditions, however, the optimal choice pattern occasionally changed. By virtue of such changes, the correspondence of the instructions with the optimal choice pattern also changed (although the instructions themselves remained constant throughout the experiment). That is, the instructions sup-

Table 1

Order of exposure to different progressive-time (PT) step sizes (in seconds). Numbers in parentheses correspond to the number of five-block sessions conducted in each condition.

Condition	Subject			
	302	303	306	308
1	PT 4(2)	PT 4(2)	PT 4(1)	PT 4(1)
2	PT 5(1)	PT 5(1)	PT 5(1)	PT 5(1)
3	PT 6(2)	PT 6(1)	PT 6(1)	PT 6(2)
4	PT 7(1)	PT 7(2)	PT 7(1)	PT 7(1)
5	PT 8(3)	PT 8(1)	PT 8(1)	PT 8(2)
6	PT 9(1)	PT 9(4)	PT 9(1)	PT 9(1)
7	PT 10(1)	PT 8(1)	PT 10(1)	PT 10(1)
8	PT 11(1)	PT 7(1)	PT 11(1)	PT 11(1)
9	PT 12(2)	PT 6(1)	PT 12(1)	PT 12(1)
10	PT 13(1)	PT 5(3)	PT 13(1)	PT 13(2)
11	PT 14(2)	PT 4(2)	PT 14(4)	PT 14(2)
12	PT 15(2)	PT 3(1)	PT 13(1)	PT 15(1)
13	PT 16(1)	PT 2(4)	PT 12(1)	PT 16(3)
14	PT 17(1)	PT 1(4)	PT 11(1)	PT 15(1)
15	PT 18(2)	PT 2(5)	PT 10(1)	PT 14(1)
16	PT 19(5)	PT 4(2)	PT 9(1)	PT 13(2)
17	PT 20(1)		PT 8(1)	PT 12(6)
18	PT 21(1)		PT 7(1)	PT 11(1)
19	PT 22(1)		PT 6(3)	PT 10(1)
20	PT 30(1)		PT 5(1)	PT 9(2)
21	PT 40(1)		PT 4(4)	PT 8(1)
22	PT 50(2)		PT 3(1)	PT 7(2)
23	PT 40(1)		PT 2(1)	PT 6(1)
24	PT 30(1)		PT 1(2)	PT 5(2)
25	PT 22(2)		PT 2(3)	PT 4(2)
26	PT 11(2)		PT 3(1)	PT 3(1)
27	PT 6(1)		PT 4(2)	PT 2(2)
28	PT 1(2)		PT 5(3)	PT 3(1)
29			PT 6(3)	PT 4(1)

ported one pattern of choices, but the optimal rate of point delivery supported a different pattern of choices. The discrepancy between the instructed and optimal patterns widened as a function of the distance from the PT 4 condition (see Figure 1).

Each subject was studied first under an ascending and then under a descending sequence of PT step sizes. Table 1 shows the order of conditions and number of sessions conducted at each. Step size was typically varied in 1-s units across conditions, but there were a few exceptions (especially for Subject 302) because of time constraints. Conditions were changed when switch points were deemed stable according to the following criteria: (a) The median point of switching from the PT to the FT schedule was constant across the final three blocks of a session, and (b) switch points were symmetrically distributed about the median. The ascending (or descending) sequence of

Fig. 2. Median points of switching from the PT to the FT schedule as a function of PT step size across the final three blocks of choice cycles in each condition. Data from the ascending sequence of conditions are represented by open squares, those from the descending sequence by closed circles, and those from additional replicated conditions by open triangles. The broken line parallel to the abscissa (inst) denotes patterns consistent with the instructions; the other broken line (opt) corresponds to the pattern that would yield the optimal rate of point delivery.

conditions was maintained until visual inspection revealed that choice patterns clearly departed from the instructed pattern. Although the exact point of this transition from instruction-appropriate to schedule-appropriate behavior was in some sense an arbitrary judgment, in nearly all cases the transition was clear-cut.

RESULTS

The data of most interest concern switching patterns from the PT to the FT schedule. Figure 2 shows the number of PT choices prior to an FT choice as a function of PT step size for all 4 subjects. Each point is a median, computed as the value of the PT schedule above and below which half of the FT choices oc-

curred, over the final three blocks of choice cycles in each condition. To remain consistent with prior work in this domain, switch points are specified as the PT value on the upcoming cycle when the FT is chosen, rather than the PT chosen on the previous cycle. The broken lines in the figure are reference points, corresponding to the instructed and optimal patterns. The optimal switch points were computed as described earlier, and were based on programmed values. (Note that at PT 30 for Subject 302, switching to the FT after one or two PT selections was optimal, in that both patterns yielded identical overall return rates: 2 points per 60 s, or 3 points per 90 s.) Because blocks were time based, optimal switch points were also affected by choice latencies. In all but a few cases, however, latencies were so

short as to have negligible effects on earnings, so the programmed rates of point delivery provide an appropriate basis for evaluating optimal performance.

All 4 subjects switched in the initial condition (PT 4) at the point supported by the instructions and by the programmed rate of point delivery. For several conditions thereafter, switching patterns were instruction appropriate rather than optimally schedule appropriate, despite losses in potential earnings. As the discrepancy between the instructions and optimal patterns of point delivery widened across the ascending sequence of PT values, instruction-appropriate patterns eventually shifted to more schedule-appropriate patterns. The point of this transition, however, varied across the 4 subjects. For Subjects 302, 303, 306, and 308, instruction-appropriate patterns were evident up to PT step sizes of 40 s (switching when the PT was 160 s), 8 s (PT of 40 s), 13 s (PT of 65 s), and 15 s (PT of 75 s), respectively.

There were many conditions in the ascending sequence in which Subject 302 switched one step prior to that specified by the instructions. However, switching patterns more closely followed the function defined by the instructed pattern than that defined by the optimal pattern, so the ascending sequence was maintained. For the other 3 subjects, the transition from instruction-appropriate to more schedule-appropriate behavior was clear and unambiguous, in each case shifting from a six-choice sequence (five PT choices before an FT) to a three-choice sequence (two PT choices before an FT). The final condition on the ascending sequence (the highest PT value to which each subject was exposed) was designated the *transition period*, in that it accompanied the transition from instruction-appropriate to more schedule-appropriate behavior.

Following this transition period, switch points remained lower and in closer accord with the optimal pattern of point delivery than in previous conditions. As the descending sequence of conditions converged on PT 4 (as the correspondence between the instruction and the contingencies improved), instruction-appropriate patterns reappeared. For Subjects 303, 306, and 308 (the 3 subjects whose exposure to the descending sequence of conditions included PT 4), instruction-appropriate behavior was regained at PT 7, PT 4, and PT

5, respectively. As the descending sequence of conditions continued beyond PT 4, optimal patterns again diverged from instructed patterns, but in a direction supporting higher rather than lower switch points. In most cases, responding did eventually change, but, with the exception of Subject 308, the changes were not always optimal. Responding in Subjects 302 and 303 changed in a direction consistent with the optimality function, whereas responding in Subject 306 remained consistent with the instructions throughout the descending sequence. Interestingly, for this latter subject, a brief return to an ascending sequence of conditions failed to recover instruction-appropriate behavior, even at step sizes (PT 3 and PT 4) at which the instructions were accurate. In Subject 306's third and final exposure to PT 4, switch points shifted in the direction opposite that supported by the instructions and the optimal rate of point delivery.

Switching patterns in transition from instruction-appropriate to schedule-appropriate behavior are of particular interest. Figure 3 shows the relative frequency and the conditional probability of an FT choice across steps in the PT sequence. (The major difference between these two measures is that the latter takes into account differences in opportunity for switches to occur at particular PT values.) The middle panel in each column shows data from the critical transition period for a given subject, and the top and bottom panels present data from the condition immediately prior to and following that period. Data in each panel are collapsed across blocks within a condition. Data in the top and bottom panels for each subject are based on a single session (the minimum required to achieve stability), whereas those in the middle panels are based on several (between two and four) sessions (see Table 1).

Unlike the switch points portrayed in Figure 2, which are based on numbers of PT choices prior to an FT, Figure 3 shows the actual PT durations at which the FT was selected. Although the transition occurred at different PT step-size values across subjects, some overall patterns are discernible (by either measure of probability). First, pretransition and posttransition distributions in each column are distinct and nonoverlapping, with posttransition modes occurring consistently two to three steps earlier in the PT schedule than pretransition modes. In other words, consistent with

Fig. 3. Relative frequency (bars) and conditional probability (lines) of an FT selection as a function of position in the PT progression across three successive experimental conditions for each subject. The middle panels present data from the condition at which the transition from instruction-appropriate to schedule-appropriate behavior occurred for each subject. The top and bottom panels show data from the condition immediately preceding and following that condition, respectively. To accommodate different PT step sizes, the abscissae on the middle panels are scaled differently than the abscissae on the top and bottom panels. All FT choices in a given condition are shown in the frequency measures. Conditional probabilities were not calculated for PT bins with fewer than two opportunities for an FT switch.

the summary measures shown in Figure 2, the majority of choices occurred earlier in the PT sequence just after the transition than under identical experimental conditions just prior to the transition. Second, the distributions of FT choices in transition are flatter, varying over a wider range of PT values, than the other distributions. In all four cases, the dispersion in these middle distributions encompassed the entire pre- and posttransition distributions. The mode of the distributions from these conditions in transition occurred at a position in the PT sequence that persisted into the next condition.

A finer grained analysis of transition patterns is provided in Figure 4, which shows successive switch points throughout the transition period for each subject, along with reference lines corresponding to instructed and optimal patterns. These data correspond to the switch points depicted in the middle panels of

Figure 3, but are portrayed here in the actual order in which they occurred. Due to between-subject differences in both the PT step size at which the transition occurred and the number of five-block sessions to achieve stability in this condition, axes are scaled individually for each subject. Switch points in the first session for each subject initially followed the instruction-appropriate pattern established in previous conditions. Switch points fell and became more variable, however, by the end of that session, before returning to the instruction-appropriate pattern briefly at the beginning of the next session. For Subjects 306 and 308, switch points eventually coincided with and stabilized at the point defined by the optimality function. For Subjects 302 and 303, whose patterns of switching rarely brought their behavior into contact with the contingencies defining optimal performance, switch points stabilized one step from optimal.

Fig. 4. Successive FT switch points in the transition period from instruction-appropriate to schedule-appropriate behavior. Every switch point from the highest PT value to which each subject was exposed is shown in the order in which it occurred. Vertical lines separate data from successive sessions. Also shown are reference lines, indicating instructed (inst) and optimal (opt) patterns. Data points correspond to the value of the upcoming PT schedule when each FT was selected. Note that the axes are scaled individually for each subject.

The transition from instruction-appropriate to more schedule-appropriate patterns had corresponding effects on each subject's earnings. Figure 5 shows the relationship between degree of instruction-appropriate behavior and the number of points per block across successive blocks of choice cycles in the transition period. Instruction-appropriate behavior was computed by dividing the median switch point by the instructed switch point for that block. Perfect compliance by this measure would thus correspond to a value of 1.0 (the horizontal line in Figure 5). For Subjects 306 and 308, degree of instruction-appropriate behavior and rate of point delivery were inversely related; switching at lower PT values yielded corre-

sponding increases in points earned. These 2 subjects, whose switching patterns were optimal by the end of the condition, earned nearly the maximum possible number of points. As mentioned previously, earnings were also affected by choice latencies, but latencies for these 2 subjects were less than 1 s on 96% of all choice cycles, so had little effect on overall earnings. For Subject 302, systematic departures from the instructed pattern yielded an even greater relative increase in earnings, despite switch points slightly exceeding optimal. For Subject 303, departures from the instructed pattern were less clearly related to block-to-block rates of point delivery.

The relationship between points earned and

Fig. 5. Relationship between instruction-appropriate behavior (closed symbols) and obtained points per block (open symbols) across successive blocks of choice cycles in the transition period. Data shown here are thus from PT 50, PT 9, PT 14, and PT 16 for Subjects 302, 303, 306, and 308, respectively. The horizontal line indicates the locus of perfect instruction-appropriate behavior. Axes are scaled individually for each subject.

PT step size can be seen more generally in Figure 6, which shows mean number of points per block across the final three blocks of each condition, expressed as a percentage of the maximum points available. This measure is preferable to an absolute measure of point frequency because it takes into account differences in point-earning opportunities created by the unequal number of choice cycles across conditions. That is, because block duration was time based, the number of choice cycles per block was determined in part by PT step size. Maximum earnings (as indicated by the horizontal line in each plot) were based on optimal rates of programmed point delivery across a 15-min block, assuming choice latencies of 0 s. Relative earnings decreased across the ascending sequence of conditions for all subjects, reaching lows of 50%, 83%, 74%, and 75% for Subjects 302, 303, 306, and 308, respectively. Earnings increased, sometimes quite sharply, in the transition from instruction-appropriate to more schedule-appropriate behavior, as reflected in the upturn at the tip of the ascending function for each subject. With the exception of Subject 303, relative earnings were higher on the descending leg of the sequence than under comparable conditions on the ascending leg of the sequence. For these 3 subjects, relative earnings seldom dropped below 90% of the maximum across the descending sequence. There were a few exceptions to this, particularly at some of the lower valued PT step sizes, where relative earnings declined somewhat. More points were actually earned during these conditions than in earlier conditions, but responding was not consistently optimal (see Figure 2).

Verbal reports were also gathered and evaluated in relation to switching patterns. Reports that specified a sequence of choices (e.g., "four blues, then a red") were separated from those that did not by two scorers unfamiliar with the research. Less than 10% of the reports specified choice sequences in a manner precise enough to quantify. The majority of reports were either too vague (e.g., "score points") or irrelevant (e.g., "I'm bored") to relate in any quantitatively direct way to the switching patterns they accompanied. Nevertheless, some of the subjects' verbal reports at crucial points in the experiment are revealing. Verbal reports of Subject 302 were entirely consistent with his choice patterns until those patterns began to deviate systematically from the instructions;

thereafter, in response to the query, "The best way to earn points is to _____," he reported, "I'm not sure."

Verbal reports of the other 3 subjects became more focused and task relevant in transition from instruction-appropriate to schedule-appropriate behavior. Immediately following the block when switching clearly broke from the instruction-appropriate pattern, Subject 303 reported, "I scored more points following my own pattern instead of the one that the instructions suggest." A few blocks later the same subject reported, "I believe that I was only supposed to score 36 points this round. By using my own pattern and not the one on the instructions, I scored 39 points."

Similarly, when responding first departed from the instructions, Subjects 306 and 308 reported on the increase in the rate of point delivery. Subject 306 declared, "THE INSTRUCTIONS ARE LIES!! . . . They CLAIM to be the way to earn the most points, but I tried my OWN little 'experiment.' I changed the order in which I selected the squares and got thirty points . . . two whole points more than when I followed your so-called 'instructions' . . ." A few blocks later this subject reported, "Apparently the best way to earn points is to just completely disregard the instructions . . . maybe." At this point, the subject announced a plan to try out different patterns, which he did for a number of blocks thereafter. His verbal reports now reported on the changes in rate of point delivery: "I'm bringing my scores up, slowly but surely. . . ." Soon after choice patterns stabilized at the optimal point of switching this subject commented on the multiple sources of control in the experiment: "I have to admit that I have absolutely no idea what this experiment is trying to find out. Whether I'll follow instructions? Or if I'll ignore the instructions to get a higher score? . . ." Reestablishing accurate instructions occasioned the following verbal report: "Well, what the hell do you know about that? Now, following the instructions is the 'way to earn the most points,' just like it says. . . ." This report came after switching had become contingency appropriate.

A roughly similar pattern of verbal-nonverbal relations was evident in the data of Subject 308. The first small, unsystematic deviation from the instructions occasioned the following report: "I scored more points this time than last time and I made a mistake." By

Fig. 6. Relative number of points per block across the final three blocks of choice cycles at each PT step size for each subject. Data from the ascending sequence of conditions are shown by open circles, from the descending sequence by closed circles, and from a second ascending sequence by open triangles. Note breaks on the ordinate axes.

the next block, all choices deviated systematically from the instructed pattern, whereupon this subject reported, "I found out the best way to earn the most points is not to pick the blue box four consecutive times. However, I'm not sure if the way I did it is the best way either. I'll have to play around next time." Early the following session, consistent with her verbal report, choice patterns became more variable and eventually stabilized at the point defined by optimal. Later in that condition she reported, "I hope that I don't get in trouble for deviating from the suggested pattern. Maybe that's the point though. Who knows?" Soon thereafter she reported, "Well no one said anything to me about changing patterns so I must not be in trouble." Several conditions later, after instruction-appropriate responding had been reestablished, a small unsystematic departure from the instructions increased the rate of point delivery and occasioned the following verbal report: "Made another mistake, but this time I got more points." As before, optimal choice patterns developed soon thereafter.

DISCUSSION

The present results join with others in revealing the multiply controlled nature of human operant performance. When the instructions were accurate, their effects were indistinguishable from optimal control by the programmed contingencies; both supported the same performance. Behavior in subsequent conditions, however, revealed that choice patterns in that first condition were under instructional control. Rather than following patterns characteristic of schedule sensitivity, choice patterns remained instruction appropriate for several conditions thereafter (ranging from 5 to 22 across subjects; see Figure 2). Such insensitivity of responding to changed reinforcement contingencies is a commonly reported feature of instructional control in laboratory settings (Baron et al., 1969; Catania et al., 1989; Galizio, 1979; Harzem et al., 1978; Hayes, Brownstein, Haas, & Greenway, 1986; Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986; Joyce & Chase, 1990; LeFrancois et al., 1988; Shimoff et al., 1981, 1986). Also consistent with prior studies, choice patterns were tightly constrained by the instructions, showing little variability, and were quick to stabilize in new conditions (Joyce & Chase, 1990).

As the instructions became less accurate, instructional control eventually was extinguished, giving way to patterns more appropriate to the programmed contingencies. Consistent with prior results (Joyce & Chase, 1990), this transition from instructional to schedule-related control occurred when choice patterns became more variable (Figure 3), and in most cases was relatively abrupt (Figure 4). These transitions were accompanied by a local increase in the rate of point delivery (Figure 5), a fact accurately reported by 3 of the 4 subjects. Following this breakdown of instructional control, choice patterns were generally in closer accord with optimal than with instructed patterns (Figure 2); this resulted in greater earnings than under corresponding PT step sizes in the ascending sequence of conditions (Figure 6). Experience with inaccurate instructions thus had enduring effects; although behavior was governed by instructions on the ascending sequence of conditions, it was more consistent with the programmed contingencies on the descending sequence. This pattern of systematic dependence on the order in which conditions are experienced—a kind of behavioral hysteresis—is consistent with the results of several studies showing that prior experience with instructions can irreversibly alter behavior, even after instructions are removed and behavior appears to be schedule sensitive (Galizio, 1979; Hayes, Brownstein, Haas, & Greenway, 1986; Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986). It also bears resemblance to patterns of hysteresis reported in choice experiments with nonhuman subjects (e.g., Baum, 1974), so it may not be unique to humans with verbal skills.

One aim of the present study was to assess systematically the effects on behavior of the correspondence between instructions and contingencies. The present procedure has some attractive features in this regard. First, because the primary data consist of sequences rather than rates, departures from optimal and instructed patterns are readily detectable (see also Vaughan, 1985). Second, subtle changes in the contingencies (through manipulations of PT step size) have small but predictable effects on reinforcement frequency. This permits correspondence between instructions and contingencies to be varied over a more continuous range of values within subjects than has been attempted in prior research.

Across the initial ascending and descending sequence of conditions, the degree to which the instruction accurately specified the contingencies was related directly to reinforcement frequency: Accuracy decreased as reinforcement frequency decreased (ascending sequence) and increased as point frequency increased (descending sequence). Between step sizes of PT 1 and PT 3, these relationships were inverted; that is, accuracy decreased with increases in reinforcement frequency (descending) and increased with decreases in reinforcement frequency (second ascending). It will be profitable in future research to sample more extensively from these latter conditions, as well as to vary the order of exposure to conditions of each type, given the hysteresis-like effects noted above. It should prove to be especially interesting, for example, to compare performance of subjects given initially accurate instructions to those given initially inaccurate instructions, and to compare both to noninstructed controls.

Units of Instructed Behavior

As defined by Skinner (1966) and others, rule-governed behavior (of which instructional control is a special case) involves relations between two sets of contingencies. One concerns the discriminative functions of the instruction, the degree to which it accurately describes a set of contingencies. Another concerns the larger social relations in which the instructions and the contingencies are embedded, the consequences arranged for compliance or noncompliance with the instruction by the surrounding verbal community. These two aspects parallel the distinction between *tracking* and *pliance*, respectively (Zettle & Hayes, 1982). With tracking, the emphasis is on correspondences between instructions and natural (non-arbitrary) consequences specified or implied by the instructions; with pliance, the emphasis is on a history of socially mediated consequences for rule following that gives rise to generalized rule-following repertoires. The difference between tracking and pliance is the difference between rule following because of the natural consequences that follow from it and rule following because of the implied social consequences for compliance with the rule. There is evidence that both were at work in the present experiment.

First, consider the evidence illustrating tracking, which can be defined here as re-

Fig. 7. Theoretical functions depicting switch points consistent with instructions and with molar and molecular contingencies of point delivery. See text for additional details.

sponding controlled by some aspect of the correspondence of the instructions with the contingencies. The relevant part of the instruction, embedded within the general instructions, consisted of the following statement: "The way to earn the most points is to select the blue flashing box, then select the solid blue box four consecutive times, then select the red box." The degree to which this instruction accurately described the nonverbal contingencies in place depends on which set of contingencies are in focus. As noted earlier, there are two potentially relevant sets of contingencies here: (a) the molar contingencies relating choice sequences to overall rates of point delivery, and (b) the more molecular contingencies relating individual schedule selections to local delays to point delivery. These latter contingencies favor switching at the point of equality ($PT = FT$) between the schedules.

Although we adopted the molar definition of schedule-sensitive behavior, there is suggestive evidence indicating that molecular contingencies may have also been important. Figure 7 shows instructed switch points, along with those predicted by a consideration of molar and molecular contingencies, across a portion of the ascending sequence of conditions. Molar and instructed switch points were computed as in Figures 1 and 2. Molecular switch

points were those that minimized the delay to the upcoming point delivery. At PT 4, the instruction was accurate with respect to the molar contingencies but was inaccurate with respect to the molecular contingencies. Between PT 4 and PT 15, the accuracy of the instruction decreased with respect to the molar contingencies but increased with respect to the molecular contingencies. At step sizes between PT 12 and PT 15, the instructed switch point was in perfect accord with the contingencies arranged for individual choices. At step sizes beyond PT 15, the instruction failed to be accurate with respect to either molar or molecular contingencies.

How should tracking, then, be defined? With respect to the molar or to the molecular contingencies? Across the ascending sequence of conditions, the molar contingencies for the most part were contacted only when they were also consistent with the instructions. Indeed, because instruction following so narrowed the range of choice patterns in these conditions, responding rarely contacted reinforcement arranged for *any* switching patterns, optimal or otherwise, other than those specified by the instructions. This permitted very little opportunity for responding to come under control of the correspondence between the instruction and the molar contingencies.

If tracking is considered in relation to molecular contingencies, however, one might expect instructional control to diminish at step sizes around PT 16. The transition from instruction-appropriate to schedule-appropriate patterns occurred for Subjects 306 and 308 at approximately this point—at PT step sizes of 14 s and 16 s, respectively. Instructional control thus weakened when the instructions became inaccurate at the molecular level of individual choices, when further instruction following would increase the delay to the upcoming point delivery.

Contact with local contingencies appears to be less relevant to the choice patterns of Subject 302, for whom instruction-appropriate behavior persisted well beyond the point at which it conflicted with molar or molecular contingencies—in one condition (PT 40) driving the PT requirements to 160 s before switching to the 60-s FT. This appears to be an instance of *pliance*, arising from the social relations of the experiment. Although no explicit conse-

quences were arranged for compliance with the instructions, the conditions of the experiment likely harnessed a prior history of rule following maintained by intermittent socially mediated consequences. Such performance reveals the power of instructions in overriding contingency-governed behavior, and may shed light on aspects of human behavior that appear to be “irrational” when considered apart from verbal functioning (Herrnstein, 1990).

Compliance of this sort is most likely when the correspondence between the instruction and behavior can be directly monitored and enforced, a condition satisfied by most laboratory research (Cerutti, 1989; Torgrud & Holborn, 1990). All of the subjects in the present study, for instance, were aware that their performance was closely monitored, which may have brought additional social contingencies to bear on their performance (recall Subject 308’s references to “mistakes” and “get[ting] in trouble for deviating from the suggested pattern”). These conditions may also give rise to *pliance-like* effects known as *demand characteristics*—behavior governed by implicit social demands of the laboratory situation that are unrelated to the variables manipulated by the experimenter (Orne, 1962). By introducing additional sources of control, demand characteristics can pose serious threats to the internal validity of an experiment. Although many of the factors that appear to guard against such effects (e.g., automated procedures that minimize undesired social contact between subject and experimenter) are standard practice in many human operant laboratories, operant experiments are not immune to demand characteristics. Close attention should be paid to all aspects of a subject’s laboratory experience, from the initial stages of recruitment to the final stages of debriefing, to minimize the influence of demand characteristics.

Instructional or Schedule Control?

When instruction-appropriate behavior finally gave way to more schedule-appropriate behavior, did instructional control disappear completely, or did it continue to interact with the contingencies on the descending leg of the sequence? In other words, did control simply shift from verbal to nonverbal contingencies, or was it modulated by the prior experience with the instructions?

The response unit that grew out of the transition from instruction-appropriate to schedule-appropriate behavior depended on the nature of the contact with the contingencies. For Subject 303, instructional control both was eliminated earlier in the ascending sequence than for the other subjects and was regained earlier on the descending sequence. These outcomes are interrelated. Two factors appear to be especially relevant. First, because instructional control ceased earliest in this subject (before the instruction grew too inaccurate) and because choices fell short of those defining optimal performance, the local improvements in earnings during the transition from instruction-appropriate to schedule-appropriate behavior were small relative to the other subjects: a relative increase of only 8%, compared to increases of 71%, 29%, and 50% for Subjects 302, 306, and 308, respectively (see Figure 5). Second, due to sometimes large but unsystematic choice latencies for this subject, fewer points were earned on the descending than on the ascending sequence (Figure 6). Deviations from the instructed pattern thus were not only less fruitful for Subject 303 than for the other subjects, but the correspondence between the instructions and the contingencies never grew as weak for this subject as it did for the others. Perhaps as a consequence, instructional control was more likely to recover in this subject than in the other subjects, for whom much wider discrepancies in the instructions and contingencies were experienced.

For Subject 308, what appeared to be selected was a response unit akin to greater schedule sensitivity: varied patterns of responding that maintained contact with changes in the contingencies (Joyce & Chase, 1990; LeFrancois et al., 1988). This is consistent with the findings that variability per se can be established as an operant unit (Neuringer, 1986). Variability tended to be greater (switching occurred across a wider range of PT values) just after a change of conditions, particularly in the conditions at which the optimal switch point also changed. This subject's choices tracked changes in the optimality function more closely than the other subjects' choices did. For Subject 302 and, to a lesser extent, Subject 306, the contingencies created and maintained a particular sequence of choices (two PTs before an FT) rather than greater

schedule sensitivity per se. Although this sequence appeared to be schedule sensitive (sometimes even optimally so), it changed very little with changes in PT step size across the descending sequence of conditions. These patterns were nearly as rigid and insensitive to changes of contingency as those previously under instructional control.

Conclusions

Behavior in the present circumstances was likely related to at least three sets of contingencies: those arranged by the procedure, those growing out of the relation between the instructions and the procedure, and those arranged (or implied) for compliance with the instructions. The initial tendency for behavior to conform to the instructions, prior to any substantive contact with the procedure, was probably part of a more general instruction-following repertoire in place prior to participation in the experiment. But behavior was also sensitive to the programmed contingencies arranged within the experiment, as evidenced by the eventual elimination of instruction following in all 4 subjects and the generally improved sensitivity to the programmed contingencies on the descending sequence of conditions.

At first glance, it may seem that such behavior was free of instructional control. But behavior did not always change in ways characteristic of optimal schedule sensitivity, so there is reason to suspect verbal involvement. It is possible, for example, that the circumstances gave rise to self-instructions (Horne & Lowe, 1993; Rosenfarb, Newland, Brannon, & Howey, 1992) that interacted with behavior as did the instructions we supplied, or that a unit of responding was established in explicit contradiction with the instructed pattern, perhaps in ways consistent with what has been variously termed *counterpliance* (Hayes, Zettle, & Rosenfarb, 1989) and *reactance* (Brehm & Brehm, 1981) (e.g., Subject 306's final exposure to PT 4, Figure 2).

Although verbal reports did become more task relevant at critical stages of the experiment, our analyses were too coarse and indirect to detect more direct verbal involvement. For example, Subject 308 (whose behavior was most sensitive to schedule changes) often re-

ported verbal strategies involving varied patterns of responding at approximately the same time that choice patterns became variable; because the report did not specify an actual sequence, however, it would not be detected in our analyses. More refined methods for measuring and manipulating verbal-nonverbal relations (e.g., Critchfield, 1993; Rosenfarb et al., 1992; Torgrud & Holborn, 1990; Wulfert, Dougher, & Greenway, 1991) will help to reveal the extent to which verbal functioning participates even in cases of apparent schedule sensitivity.

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Received December 13, 1993

Final acceptance July 25, 1994