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A COLLATERAL EFFECT OF REWARD PREDICTED BY MATCHING THEORY

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Matching theory describes a process by which organisms distribute their behavior between two or more concurrent schedules of reinforcement (Herrnstein, 1961). In an attempt to determine the generality of matching theory to applied settings, 2 students receiving special education were provided with academic response alternatives. Using a combined simultaneous treatments design and reversal design, unequal ratio schedules of reinforcement were varied across two academic responses. Findings indicated that both subjects allocated higher rates of responses to the richer schedule of reinforcement, although only one responded exclusively to the richer schedule. The present results lend support to a postulation that positive reinforcement may have undesirable collateral effects that are predicted by matching theory (Balsam & Bondy, 1983).

DESCRIPTORS: concurrent schedules, matching theory, basic research, positive reinforcement

The term *matching* refers to an operant process describing how organisms distribute their behavior between two or more concurrent schedules of reinforcement (Herrnstein, 1961). Herrnstein demonstrated that the distribution of behavior among concurrently available alternatives is lawful and is dependent on the rate of reinforcement for each alternative schedule. Specifically, the relative frequency of responding to a given alternative closely approximates the relative frequency of reinforcement obtained from that alternative. This finding forms the basis for the matching law, a mathematical description of the orderly allocation of behavior among response alternatives in proportion to obtained reinforcement. Since Herrnstein's classic study, considerable research with animals has confirmed the basic tenets of the matching law (de Villiers, 1977). Several replications with human subjects have further shown that matching theory has generality across species. Pierce and Epling (1983) reviewed the matching literature with human subjects and found that most studies confirmed that humans also distribute their behavior in relation to the rate of reinforcement for response alternatives. Researchers who have failed to observe matching with humans have speculated that some subjects formulate inaccurate rules regarding reinforcement contingencies that may interfere with matching (Lowe & Horne, 1985).

Although the results of basic research generally support matching theory, its applied value is as yet uncertain. The overwhelming majority of human matching studies have been conducted under controlled laboratory conditions and with response topographies that are not applied in nature (e.g., lever or key pressing, contrived discussion). Nevertheless, Pierce and Epling (1983), McDowell (1988), and Myerson and Hale (1984), among others, have argued that the matching theory may have practical implications that should not be overlooked by applied behavior analysts. Under natural conditions, humans are presented concurrently with an array of response choices. For example, at any given moment an elementary school student may complete worksheet problems, ask a question of the teacher, leave his or her seat, talk to a peer, read a book, and so on. According to matching theory, the student will engage more often in the alternatives

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whose relative rate of reinforcement is greater and less often in behavior that results in comparatively less reinforcement. Thus, explanatory models that include concurrent schedules and matching may provide a more complete understanding of behavior in applied settings than the three-term contingency alone (Myerson & Hale, 1984; Pierce & Epling, 1983).

The present investigation concerns a potential collateral effect of reward that is predicted by matching theory (Balsam & Bondy, 1983). Introduction of a reinforcement program to increase the rate of a given target behavior can have concomitant effects on other response alternatives. This reasoning underlies the use and effectiveness of differential reinforcement of alternative behavior (DRA) as an intervention for reducing aberrant behavior. Increasing the rate of reinforcement for an adaptive target response relative to the rate of reinforcement for an aberrant behavior can result in more adaptive and less maladaptive behavior as the subject redistributes his or her behavior in accord with the relative rates of reinforcement for response alternatives (McDowell, 1988; Myerson & Hale, 1984).

However, Balsam and Bondy (1983) observed that collateral decrements in concurrent operants following introduction of a reinforcement intervention are not limited to aberrant behavior. Increasing response rates for an appropriate target behavior can also have undesirable effects on concurrent adaptive responses. Matching theory predicts that as the relative richness of reinforcement favors one behavior, responding on concurrent alternatives will decrease, regardless of whether the alternative behaviors are aberrant or adaptive. Thus, it seems plausible that a student may complete more worksheet problems in response to a token economy, but, as an unplanned collateral effect of reward, emit fewer adaptive responses such as asking or answering questions, listening to lectures, reading (assigned or incidental), or working on topics that are not subject to the planned reinforcement contingencies. Moreover, there may be the danger that the student will respond exclusively on the schedule with superior reinforcement in order to maximize his or her reinforcement (Herrnstein, 1970; Herrnstein & Loveland, 1975).

The purpose of the present study was to investigate the generality of matching in an applied setting. The goal was to determine whether students presented with two academic response alternatives on concurrent reinforcement schedules would distribute their behavior between the alternatives in approximate proportion to rate of reinforcement supplied for the two responses. A further objective was to investigate whether subjects would maximize their reinforcement and respond predominantly on the richer schedule, thereby illustrating an unplanned collateral effect of reward postulated by Balsam and Bondy (1983).

EXPERIMENT 1

METHOD

Subject and Setting

Glenn was a 16-year-old student enrolled in a private school and day treatment center for adjudicated delinquents. His educational goal was to obtain a General Education Degree (GED) rather than complete requirements for a high school diploma. Although his IQ test scores placed him in the average range of intellectual functioning, standardized achievement tests and his classroom performance indicated deficits of 3 to 5 years below grade level across academic subjects. In general, Glenn showed little interest in academic tasks and completed them only when instructed to do so. All sessions were conducted in the classroom during break or lunch periods with only the teacher and subject present.

Assessment for Task and Reinforcers

Glenn was administered a *Wide Range Achievement Test* to identify deficits in academic subjects that could be targeted for the study. His performance was poorest in math, showing a 4.2 grade equivalent with similar deficiencies apparent in multiplication and division problems with three decimal places. Further informal testing suggested that slow computational skills partially accounted for his low achievement score. This indicated the need for frequent practice in computing multiplication and division tasks, both of which appear on the GED examination.

Reinforcer sampling was conducted by presenting Glenn with two 10-item lists of food products and instructing him to select his favorite item from each list. Glenn's top selections were Baby Ruth® candy bars and Doritos® corn chips.

Target Behaviors and Data Collection

The behaviors exposed to concurrent schedules of reinforcement were completed, three-digit multiplication and division problems. A completed problem was defined as a final answer plus answers to all steps in the arithmetic problem (i.e., a product or quotient for each decimal place in the problem). Math problems were presented individually on task cards (8 cm by 10 cm) with sufficient space to calculate answers. Two observers independently scored each task card as complete or incomplete at the end of all sessions. Observers' ratings were in agreement 100% of the time. The dependent measure was the rate of problems completed (per minute) and was derived by dividing the number of problems per session completed by the duration of each session (15 min).

Procedures

Baseline. The classroom teacher and the subject were seated across from each other at a table (1 m^2). Two stacks of task cards (30 per stack) were positioned facing and parallel to the subject. One stack contained multiplication problems and the other consisted of division problems. The right–left position of the stacks was alternated across sessions to control for possible effects of stack position. Task cards were randomly selected from a large pool of problems prior to each session. Math problems were not returned to the pool once the subject completed them to ensure that problems were not repeated. The teacher provided the following instructions to the subject at the start of each session: "Here are two tasks for you to do. You may do multiplication or division problems, whichever you like. They will help you do better in math class and on the GED exam. You have 15 min to work on them." The teacher remained seated while Glenn worked on the problems and provided no feedback or reinforcement for completion of the tasks.

Equal VR 2 schedules of social reinforcement. Procedures were identical to baseline except that the teacher provided praise on a Variable-Ratio 2 (VR 2) schedule immediately after completion of multiplication *and* division problems. Examples of praise were "That's great, Glenn," "You're really doing well," and "Keep up the good work." Thus, both responses were placed on equal concurrent schedules of reinforcement.

Equal VR 2 schedules of edible reinforcement. This condition differed from baseline only by providing edible reinforcers contingent on problem completion. The teacher delivered a small portion of candy bar to the subject on a VR 2 schedule for completing multiplication problems. Completion of division problems resulted in two chips delivered on a VR 2 schedule. Again, both academic responses were placed on equal concurrent schedules of reinforcement.

Equal VR 2 schedules with edible reinforcers reversed. The purpose of this condition was to assess possible interactions between type of reinforcer and type of math problem. Procedures were identical to the previous phase except that chips were provided for completion of multiplication problems and candy was provided for completed division problems. Both reinforcers were provided on equal VR 2 schedules.

Unequal schedules favoring multiplication. This condition assessed the effects of unequal concurrent schedules on the subject's allocation of behavior between the response alternatives. Procedures were the same as the previous phase, including the task–reinforcer pairings, with the following exception. Completion of multiplication problems resulted in delivery of chips on a continuous reinforcement schedule (CRF), and completed division problems remained on a VR 2 schedule. The subject was not informed of the change in reinforcement schedules.

Unequal schedules favoring division. This condition reversed the reinforcement schedules for the two response alternatives. Completed multiplication problems were reinforced with chips on a VR 2 schedule and completed division problems resulted in candy on a CRF schedule. All other procedures remained identical to the preceding phase.

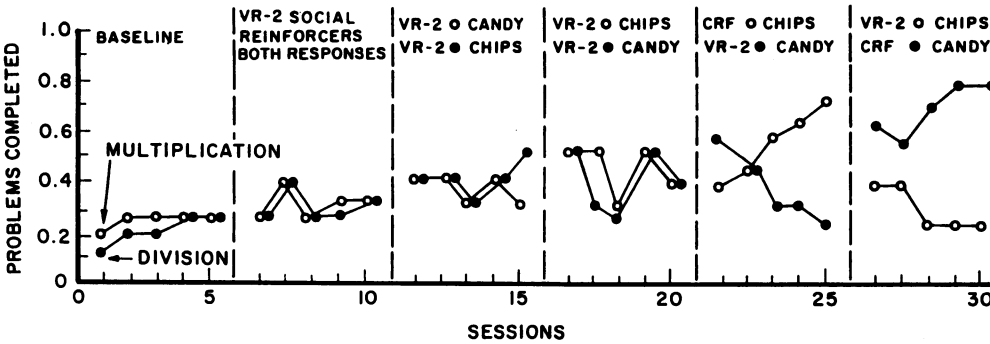

Figure 1. Rate of math problems completed (per minute). Multiplication and division problems are concurrent alternatives subject to equal and unequal schedules of reinforcement across phases of the study.

Experimental Design

The effects of the concurrent schedules of reinforcement on the rate of problem completion were assessed using a combined simultaneous treatments design and reversal design. Effects were evaluated across the following sequence of phases: (a) baseline, (b) equal schedules of social reinforcement, (c) equal schedules of edible reinforcement, (d) reversed equal schedules of edible reinforcement, (e) unequal schedules of edible reinforcement, and (f) reversed unequal schedules of edible reinforcement.

Results

Figure 1 illustrates the subject's rate of math problems completed (per minute) across the six experimental phases. During baseline, Glenn generally distributed his work behavior evenly between multiplication and division problems. The mean rate for multiplication problems was 0.26 compared to 0.21 for division problems. In the second phase, introduction of social reinforcers on a VR 2 schedule for both responses resulted in a slight increase in work rate and, again, little difference between the two types of problems. Glenn's average rate was 0.32 for multiplication tasks and 0.30 for division problems. Edible reinforcers on equal VR 2 schedules were used in the third phase to produce a larger increase in the subject's work rate. Mean rate of completed multiplication problems was 0.40 versus 0.37 for division tasks. Holding the rate of reinforcement equal and constant, the pairings of type of edible reinforcer with type of math problem were reversed in the fourth phase to assess possible interactions that could confound interpretation of the data. Again, Glenn distributed his work responses evenly between the alternatives, averaging 0.43 and 0.39 problems completed per minute for multiplication and division problems, respectively. In the fifth phase, Glenn completed more multiplication problems (0.57 per minute) on the richer CRF schedule than division tasks (0.40 per minute) that remained on the VR 2 schedule of reinforcement. In the final phase, this behavior pattern reversed when the CRF schedule was applied to division problems and multiplication tasks were returned to a VR 2 schedule. Glenn's average rate was 0.32 for multiplication tasks and 0.72 for division problems.

EXPERIMENT 2

Method

Subject and Setting

The participant in the second experiment was Phil, a 12-year-old boy functioning in the profound range of mental retardation. Phil was ambulatory and had good gross- and fine-motor skills. He exhibited a variety of autistic-like behaviors including hand flapping and gazing, stereotyped manipulation of objects, and repetitive vocalizations. The subject occasionally emitted a variety of aggressive and disruptive behaviors in the classroom. Phil was enrolled in a life-skills program for children with developmental disabilities at a private day school. The curriculum emphasized training in self-care, community living skills (i.e., shopping, bus riding), and prevocational skills. Experimental sessions were conducted in a work area located in the corner of Phil's classroom.

Assessment for Tasks and Reinforcers

Phil was presented with five assembly tasks that he was able to complete and that were used in his prevocational training program. His teacher instructed him to assemble five of each item in order to determine his average assembly time per task. Pen assembly and bagging silverware were selected for the study because it required Phil approximately 12 min to complete five of each task. Pen assembly consisted of (a) inserting an ink cartridge into the lower half of the pen body, (b) placing the upper half of the pen body atop the protruding ink cartridge, and (c) screwing the upper and lower halves of the pen body together. Assembling silverware entailed placing a plastic knife, fork, and spoon into a clear plastic bag.

Edible reinforcers were used in this experiment because Phil's teachers reported that he was generally unresponsive to praise. A reinforcer sampling procedure was used to select two preferred food items by presenting the subject with a variety of food items and allowing him to eat without restriction for 5 min. Bite-size peanut butter cups and M&M®s were consumed more frequently than other food items.

Target Behaviors and Data Collection

The target behaviors subject to concurrent reinforcement schedules were completely assembled pens and bags of silverware. A complete assembly task was defined as one in which all of the steps defined above were performed by the subject. Partially assembled tasks were disregarded. Data collection procedures and calculation of the dependent measure, rate of tasks completed (per minute), were identical to Experiment 1. Two independent observers collected interobserver agreement measures for 12% of the sessions. Observers were in agreement on the number of completely assembled tasks 100% of the time.

Procedures

Baseline. The subject was seated opposite the school psychologist at a rectangular table during the 15-min sessions. The pen and silverware assembly tasks were positioned facing the subject in separate shallow boxes. The right–left position of the tasks was alternated across sessions. Each session began with the following instructions, "Phil, please work on the pens and silverware tasks." The psychologist remained seated while Phil performed the tasks and provided no prompts or reinforcement for task completion.

Equal VR 2 schedules and amounts of reinforcers. Procedures during Phases 2 and 4 of the study were identical to baseline with the following exception. The psychologist provided one peanut butter cup on a VR 2 schedule immediately following completed silverware tasks. One M&M® was delivered to the subject on a VR 2 schedule after completion of pen assembly tasks. This procedure placed both responses on equal concurrent VR 2 schedules with equal amounts of reinforcers (i.e., one piece of candy per reinforcement).

Equal VR 2 schedules with reinforcers reversed. Procedures were identical to the previous phase except that one peanut butter cup was provided for completely assembled pens and one M&M® was provided for correctly bagged silverware. Both reinforcers were provided on VR 2 schedules. This phase was designed to detect possible interactions between task type and reinforcer type.

Unequal schedules and reinforcer amounts favoring silverware. This condition assessed the combined effects of unequal concurrent schedules plus unequal reinforcer amounts on Phil's distribution of work between the two alternatives. Procedures were the same as the preceding phase, including the task–reinforcer pairings, except for the schedules and amounts of reinforcers provided for each task. Completed silverware tasks resulted in two peanut butter cups delivered on a CRF schedule. Reinforcement for pen assembly tasks remained one M&M® delivered on a VR 2 schedule. These procedures were in effect during Phases 5 and 7.

Unequal schedules and reinforcer amounts fa-

voring pens. This condition reversed the reinforcement schedules and amounts with the type of task. Assembled pens were reinforced with two M&M®s on a CRF schedule and reinforcement for bagged silverware returned to one peanut butter cup on a VR 2 schedule. All other procedures remained identical to baseline.

Experimental Design

A combined simultaneous treatments design and reversal design were used to evaluate the effect of the concurrent reinforcement schedules on the subject's work rate. The subject experienced the above conditions in the following sequence: (a) baseline; (b) equal VR 2 schedules and amounts of reinforcement, (c) equal VR 2 schedules and amounts with reinforcers reversed, (d) equal VR 2 schedules and amounts of reinforcement (same as b), (e) unequal schedules and reinforcer amounts favoring silverware, (f) unequal schedules and reinforcer amounts favoring pens, and (g) unequal schedules and reinforcer amounts favoring silverware.

RESULTS

The subject's rate of completely assembled tasks is presented in Figure 2. During baseline, Phil showed a preference for pens, completing an average of 0.36 units per minute compared to a rate of only 0.06 for the silverware task. Introduction of equal VR 2 reinforcement schedules for both tasks in Phase 2 resulted in increased production of both tasks; however, a preference for the pen task (or the reinforcer paired with it) was still apparent. Mean rates were 0.55 and 0.37 for pens and silverware, respectively. Reversal of the reinforcers while holding the VR 2 schedules equal resulted in an initial preference for the pen task that became less evident over the course of the third phase. This initial preference for pens resulted in a mean rate of 0.51 for pens and 0.25 for silverware. In Phase 4, a return to the original task–reinforcer pairings produced little difference in the subject's completion of the tasks; the average rate was 0.51 for the pen task and 0.41 for the silverware task.

The effects of unequal schedules and reinforcer amounts were assessed in Phases 5 through 7. In the fifth phase, a CRF schedule and double the amount of peanut butter cups for silverware completion resulted in a mean rate of 0.46 compared to a return to baseline levels of performance (0.35) for the pen task that remained on a VR 2 schedule. Moreover, differences between the two tasks became more apparent as the phase progressed. The schedules and reinforcer amounts were reversed in the sixth phase. After initial undifferentiated performance, Phil responded almost exclusively on the CRF schedule with double the reinforcer amount (i.e., the pen task). Mean rates for the entire phase were 0.45 and 0.21 for pens and silverware, respectively. In the final phase, the subject appeared to discriminate quickly between the two schedules when they were reversed. He responded at a high rate and almost exclusively to the richer reinforcement schedule that was applied to silverware. Mean rates were 0.88 for silverware and only 0.13 for pens.

DISCUSSION

Both experiments investigated the relevance of matching theory (Herrnstein, 1961; McDowell, 1988) in applied educational settings. Subjects with very different functioning levels, using different educational tasks, tended to distribute their academic responses between two concurrently available alternatives in proportions that approximated those predicted by matching theory. We will limit our evaluation of matching to qualitative descriptions of data patterns because our data do not strictly conform to conventional criteria for quantitative analysis (see Fuqua, 1984, McDowell, 1981, Nevin, 1984, and Pierce & Epling, 1983, for discussions of limits to quantitative analysis of applied data).

The effects of rate of reinforcement on concurrent operants are evident in the last three phases of Experiment 1, in which task and reinforcer pairings were held constant (see Figure 1). Provided with equal rates of reinforcement for doing multiplication and division problems (Phase 4), Glenn al-

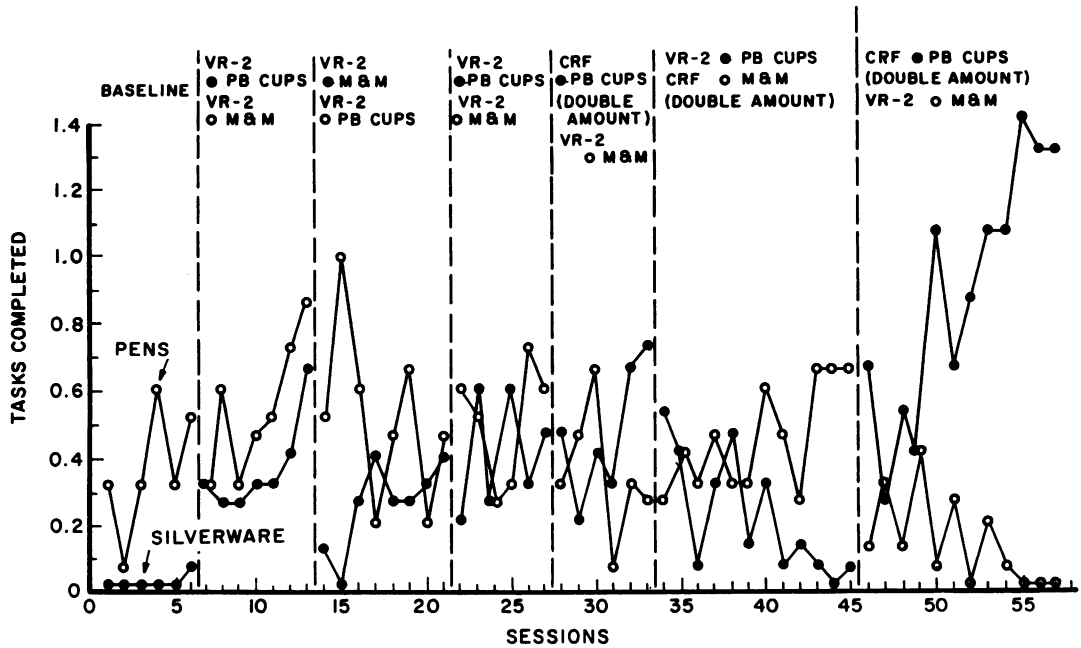

Figure 2. Rate of assembly tasks completed (per minute). Pen and silverware assembly tasks are concurrent alternatives subject to equal and unequal reinforcer schedules and amounts across phases of the study.

located his behavior almost evenly between the two academic alternatives. In the next two phases, doubling the rate of reinforcement for one alternative while holding the rate constant for the other alternative affected both responses in a manner generally consistent with matching theory. Although response rates increased consistently for the alternative yielding a higher rate of reinforcement, response rates also decreased relative to Phase 3 levels for the other alternative, even though reinforcement rate for this response remained unchanged.

A somewhat similar pattern of results was evident for Phil during Phase 2 and Phases 4 through 7 of Experiment 2, in which task and reinforcer pairings were constant (see Figure 2). Equal rates of reinforcement for both alternatives resulted in a slight preference for pen assembly during Phase 2 that became less apparent during identical conditions in Phase 4. Thus, equal rates of reinforcement resulted in similar response rates as the subject alternated between the two assembly tasks. To make unequal reinforcement conditions more discriminable for Phil, reinforcer rate and amount were doubled for one alternative during Phases 5 through 7. Under these conditions, Phil allocated more work responses to the alternative yielding greater reinforcement. This preference became increasingly distinct to the point where Phil responded exclusively on the option with greater reinforcement, although reinforcement for the other alternative remained unchanged.

These findings tend to support a postulation by Balsam and Bondy (1983) that positive reinforcement may have unplanned collateral effects that are predicted by matching theory. Introduction of a reinforcement contingency not only influences the target behavior but can have a suppressive effect on other adaptive responses. Balsam and Bondy noted that individuals inevitably adjust their allocation of behavior according to the relative richness of reinforcement across response alternatives. Thus, increasing the rate of reinforcement for one response is likely to have undesirable effects on other behaviors that may be adaptive for the individual. This was the case for both subjects in the present study. When reinforcement favored one type of math problem in Experiment 1, response rates on the alternative dropped to or below baseline levels. The effect on Phil's work rate was more dramatic, as he tended to respond almost exclusively to the option that yielded greater reinforcement.

We were restricted to a qualitative analysis of our data, in part, because natural environments contain variables, in addition to reinforcement rate, that are likely to affect response patterns under concurrent schedules. To approximate natural conditions, we used different response options and different edible reinforcers. However, because the precise influence of these variables on matching is unknown, it may be premature to invoke a literal translation of the matching law to applied settings. For example, matching theory predicts exclusive preference for the smaller ratio on concurrent ratio schedules of reinforcement (Herrnstein & Loveland, 1975). However, exclusive preference is dependent on reinforcers being equal or substitutable. In the present study, only Phil showed exclusive preference. Although Glenn adjusted his behavior in response to unequal reinforcement rates, he did not maximize reinforcement by responding solely on the smaller ratio. We can speculate that exclusive preference may have been discouraged because to do so would have eliminated reinforcer variety. The response patterns observed by Glenn yielded both a high rate of reinforcement and reinforcer variety. Because this response pattern is not predicted entirely by matching theory, additional research is needed to delineate the effects of such variables on matching.

We can suggest some directions for future research that may improve the predictive value of matching theory for natural settings. The availability of qualitatively different reinforcers in natural environments is likely to influence response allocation to an unknown extent (de Villiers, 1977). Matching can only be predicted on the basis of rate of reinforcement if reinforcers such as teacher attention, interaction with peers, tokens, grades, content of reading passages, and other reinforcers are substitutable. Because this assumption is often untenable, future research should directly examine the effects of reinforcer value on matching under natural conditions. This could be accomplished by first establishing a baseline response rate under concurrent variable-interval (VI) schedules using one type of reinforcer, and then applying a reinforcer of different value to one alternative in order to assess changes in response allocation when reinforcer values are unequal. The situation becomes more complex when qualitatively different reinforcers interact, as in the case of food and water in animal research (Brown & Herrnstein, 1975). A preference for food can produce collateral increases in responses that result in water due to the tendency to drink after eating. Such an interaction may come into play when public praise for a student's academic behavior induces the student to alternately engage in disruptive actions that produce laughter from his peers and avoid the appearance of receiving preferential treatment from the teacher.

Similar reasoning suggests that matching may also be affected when alternative behaviors have unequal response requirements. For example, a student may obtain teacher attention at comparable rates for calling out both correct and incorrect answers to teacher questions. We can speculate that, when formulating a correct answer requires more "effort," the option of offering an incorrect answer may be preferred even though reinforcement rates for both types of answers are roughly equivalent. The effects of differing response requirements on matching could be investigated in a manner similar to that suggested for different reinforcer values.

Unequal reinforcer values and response requirements may result in departures from ideal matching known as *undermatching* and *bias* (Pierce & Epling, 1983). Undermatching occurs when subjects favor the alternative with the higher rate of reinforcement, but the proportion of responding on that alternative is lower than the proportion of reinforcement derived from it. The magnitude of undermatching generally varies with response and reinforcement ratios. Bias, on the other hand, refers to a constant preference for one alternative as response and reinforcer ratios vary. There may be some practical implications for detecting a systematic departure from ideal matching. For instance, when a DRA intervention to reduce aberrant behavior is ineffective despite a rich schedule of reinforcement for the alternative response, the behavior analyst may select qualitatively different reinforcers or reduce the response requirements for the alternative behavior. Such actions are not predicted by matching theory alone, but may well follow from future research identifying some of the determinants of undermatching and bias in various natural settings.

Our final suggestion for further study is related to recent research on response covariation. Several studies have shown that procedures that increase adaptive behavior (e.g., compliance) often result in unplanned collateral reductions in aberrant behavior (e.g., Cataldo, Ward, Russo, Riordan, & Bennett, 1986; Parrish, Cataldo, Kolko, Neef, & Egel, 1986; Russo, Cataldo, & Cushing, 1981). These collateral reductions in aberrant behavior are likewise predicted by matching theory. That is, when reinforcement contingencies are altered to favor compliance, reinforcement for aberrant behavior may become relatively unfavorable, and subjects are likely to adjust their response allocation accordingly. The prevalence of this covariation suggests that collateral effects of reinforcement should be monitored for both aberrant and adaptive behavior. We may have reached the point where evaluation of behavioral interventions requires weighing the beneficial effects on the target behavior against possible undesirable collateral effects on concurrent responses.

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