JOURNAL OF APPLIED BEHAVIOR ANALYSIS 1992, 25, 691–699 NUMBER 3 (FALL 1992)

EFFECTS OF REINFORCER RATE AND REINFORCER QUALITY ON TIME ALLOCATION: EXTENSIONS OF MATCHING THEORY TO EDUCATIONAL SETTINGS

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We examined how 3 special education students allocated their responding across two concurrently available tasks associated with unequal rates and equal versus unequal qualities of reinforcement. The students completed math problems from two alternative sets on concurrent variable-interval (VI) 30-s VI 120-s schedules of reinforcement. During the equal-quality reinforcer condition, high-quality (nickels) and low-quality items ("program money" in the school's token economy) were alternated across sessions as the reinforcer for both sets of problems. During the unequal-quality reinforcer condition, the low-quality reinforcer was used for the set of problems on the VI 30-s schedule, and the high-quality reinforcer was used for the set of problems on the VI 120-s schedule. Equal- and unequal-quality reinforcer conditions were alternated using a reversal design. Results showed that sensitivity to the features of the VI reinforcement schedules developed only after the reinforcement intervals were signaled through countdown timers. Thereafter, when reinforcer quality was equal, the time allocated to concurrent response alternatives was approximately proportional to obtained reinforcement, as predicted by the matching law. However the matching relation was disrupted when, as occurs in most natural choice situations, the quality of the reinforcers differed across the response options.

DESCRIPTORS: matching theory, choice, reinforcer quality, reinforcer rate, concurrent schedules

The matching law (Baum, 1974; Herrnstein, 1961, 1970), as a mathematical model for predicting response allocation across concurrent schedules of reinforcement, offers applied behavior analysts a methodology and theoretical framework for studying choice (Baum & Rachlin, 1969; McDowell, 1988; Rachlin, 1989). Within this framework, any behavior and its controlling contingency are considered one option among an array of concurrently available alternative responses and their accompanying schedules of reinforcement. How and why an individual allocates behavior across response alternatives is the subject of matching research (Davison & McCarthy, 1988; de Villiers, 1977; Pierce & Epling, 1983). According to the matching law, the distribution of behavior across response alternatives tends to be proportional to the reinforcement received from those alternatives.

The vast majority of matching studies have been

This research was supported by Grant HO23A00027-90A from the U.S. Department of Education, Office of Special Education Programs to the Devereux Foundation. The opinions expressed herein do not necessarily reflect the position or policy of the U.S. Department of Education.

We gratefully acknowledge the support of Steven Pfeiffer, Steven Woolf, and the staff of Gateway School in conducting this study.

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conducted with nonhuman subjects under highly controlled laboratory conditions (Davison & McCarthy, 1988). Systematic replications with humans using experimental arrangements that closely parallel nonhuman experiments have generally shown that the matching law may also describe human behavior in the operant laboratory (Pierce & Epling, 1983). These robust findings have prompted several behavior analysts to encourage applied researchers to examine the relevance of the matching law to work in clinical and educational settings (McDowell, 1982, 1988; Myerson & Hale, 1984; Pierce & Epling, 1983).

However, direct translations of the matching law and other basic research findings to applied settings may be hampered significantly by important differences between laboratory conditions and complex human environments (Baer, 1981; Fuqua, 1984). One of the most striking differences between basic matching studies and natural contingencies for human behavior is the variation in reinforcers available for alternative behaviors. In a typical matching experiment, contingent reinforcers are arranged according to concurrent variable-interval variable-interval (VI VI) schedules of reinforcement for two different behaviors occurring in the presence of distinct stimuli. This arrangement holds the quality of the reinforcer constant (e.g., a specific type of food) and varies the rate of reinforcement in different VI schedules. However, for humans in natural settings, the quality of the reinforcer often varies across response alternatives (e.g., praise vs. physical contact, money vs. tokens, jazz vs. classical music). Under these conditions, reinforcer quality may interact with the rate of reinforcement to produce patterns of response allocation not predicted by the matching law. A limited number of nonhuman studies have supported the hypothesis that reinforcers of different qualities can disrupt the matching relation and produce a bias toward the higher quality reinforcer that is independent of reinforcer rate (e.g., wheat vs. brain stimulation in rats, Hollard & Davison, 1971; hay vs. dairy meal in cows, Matthews & Temple, 1979; and buckwheat vs. hemp vs. wheat in pigeons, Miller, 1976).

A few studies have expressly investigated the applicability of matching theory to socially important human behavior. McDowell (1981) and Martens and Houk (1989) found that natural covariations between self-injurious behavior and parental attention and between disruptive behavior and teacher attention, respectively, were predicted by Herrnstein's (1970) single-alternative formula of the matching law (see McDowell, 1988, for a description of this methodology). That is, time allocated to the target behavior was an increasing function of the rate of attention provided by adults, with the function approximating the hyperbolic curve defined by the matching law. In two experimental studies, Mace, McCurdy, and Quigley (1990) and Conger and Killeen (1974) studied academic skills and social interaction, respectively, on concurrent schedules of reinforcement. In the Mace et al. (1990) study, concurrent ratio schedules of reinforcement applied to arithmetic or vocational tasks resulted in near-exclusive responding on the richer schedule, a finding consistent with basic research using concurrent ratio schedules (Herrnstein & Loveland, 1975). In the only study of social behavior under concurrent VI VI schedules, Conger and Killeen (1974) had each of their subjects discuss drug use with three experimenters. Two of the experimenters provided complimentary statements contingent on conversation directed at the experimenters according to independent VI schedules, while the third experimenter moderated the discussion. As predicted by the matching law, subjects divided their conversation between the two experimenters in approximate proportion to the rate of attentive comments supplied by the experimenters.

The results of research extending matching theory to applied situations are encouraging because they show that when circumstances in the applied setting are analogous to those in the operant laboratory (i.e., reinforcer rate is varied and the type of reinforcement is constant), humans will allocate their behavior across response alternatives in proportions predicted by basic matching research. The studies are preliminary, however, because the type and quality of the reinforcers often vary across alternatives in natural environments. If reinforcer quality interacts with reinforcer rate, matching allocation to rate of reinforcement will be disrupted, and the accuracy of predictions based on the matching law alone will diminish.

Our objectives in the present research were twofold. First, we sought to replicate the applied studies showing that behavior is sensitive to rates of reinforcement arranged in concurrent schedules when reinforcer quality is constant and to extend the scope of investigation to students performing academic tasks. Second, we hypothesized that arranging reinforcers of different qualities on concurrent VI VI schedules would disrupt the matching relation and produce a bias toward the response and schedule with the higher quality reinforcer.

METHOD

Participants and Setting

Three students in a special education program for adolescent and young adult females with severe emotional disturbance or behavior disorders and learning difficulties served as participants. The students were referred by their teachers because of their need for assistance in completing instructional tasks and for practice in arithmetic skills. They were enrolled in the study following provision of informed consent by the participants and their guardians.

Thyme, aged 18 years, was diagnosed as having "organic mental syndrome" and as functioning within the borderline range of intelligence. Her scores on the California Achievement Test yielded a 7.2 grade level in math and an overall grade level of 7.3. Ali, aged 14 years, and Kate, aged 18 years, were each diagnosed as having a "disruptive behavior disorder" and as functioning within the borderline range of intelligence. Their WISC-R IQ scores were 76 and 63, respectively. Educational tests yielded a 7.0 grade level in math for Ali and a 3.9 grade level in math for Kate. Sessions were conducted in a small office at the school, with the experimenter seated across from the participant at a table.

Experimental Conditions and Procedures

Two 10-min sessions were conducted per day, 3 days per week, for each participant. Immediately before the start of each session, the student was asked whether she preferred to work for nickels or their equivalent in "program money." Program money was used in the school's token economy system and could be exchanged for community outings and other privileges or special events, as well as items from the school store (e.g., snacks, cosmetics). Nickels (which the students always identified as the preferred item) and program money served as the high- and low-quality reinforcers, respectively.

During each session, two stacks of problems printed, respectively, on yellow and green index cards were placed on top of the table in front of the student. The problem on each card was the same across the two stacks and consisted of two-digit by one-digit multiplication (without a carrying operation) for Thyme, three-digit by one-digit multiplication (with a carrying operation) for Ali, and three-digit by three-digit addition (without a carrying operation) for Kate. The student was given a standard instruction, "You can earn nickels (program money) [depending on the condition in effect] doing these math problems. You may work on either stack of problems as you choose. You may start when I say 'begin.' " For sessions using program money, the student was also told, "Each chip is worth 5 cents in program money."

Correct responses to problems on the yellow and green cards were reinforced on concurrent VI 30-s VI 120-s schedules. The nickel or chip (depending on the condition in effect) was deposited in a transparent plastic cup the same color as, and directly behind, the respective stack of problems. Reinforcement was delivered contingent on the first correctly completed problem after the reinforcement interval (signaled to the experimenter by audiotape through an earphone) had elapsed for the respective schedule. Following an incorrect response, the experimenter marked the card with an X.

Prebaseline. Preliminary sessions were conducted to determine the students' sensitivity to the VI reinforcement schedules under the equal-quality reinforcer condition described below and subsequently to facilitate discrimination of those contingencies. Procedures were identical to the equal-quality reinforcement condition except that a digital kitchen timer, signaling the remaining time within the respective reinforcement interval, was placed behind each of the two stacks of problems facing the student. When the students consistently allocated their behavior in patterns predicted by the schedules, the timers were removed and the experimental conditions described below were initiated.

Equal-quality reinforcers. Performance was assessed under two independent sets of concurrent VI 30-s VI 120-s schedules. Nickels and program money, respectively, were alternately used as the reinforcers across sessions. Thus, reinforcer quality was held constant across the two stacks of arithmetic problems within each set of concurrent schedules. The purposes of this condition were to confirm that both nickels and program money operated as reinforcers and to determine the extent of matching under equal-quality reinforcer conditions as a standard against which the effects of unequal-quality reinforcers could be compared.

Unequal-quality reinforcers. The experimenter informed the student that the student would be able to earn nickels, program money, or both during the session for doing the math problems. Schedules of reinforcement for performance of problems on yellow and green cards were identical to the equal-quality reinforcer condition, but the high-quality reinforcer (nickels) was delivered on the VI 120-s schedule for green-card problems, and the low-quality reinforcer (program money) was delivered on the VI 30-s schedule for yellow-card problems.

Equal- and unequal-quality reinforcer conditions were alternated using a reversal design.

Data Collection and Interobserver Agreement

Data collectors recorded time allocated to each of the response alternatives within continuous 1-min intervals using two stopwatches. Each stopwatch was started when, and remained activated while, the student was visually oriented to a problem from that stack. In addition, the number of problems completed correctly and incorrectly for each of the response alternatives was counted at the end of each session. A second observer collected interobserver agreement data on 32% of the sessions across conditions. An agreement for time allocation was defined as both observers recording the same duration within a 1-min interval plus or minus 2 s. A total of seven disagreements occurred throughout the experiment. Agreement for response rate (both observers recording the same number of problems completed) was 100%.

Data were also collected on the number of times reinforcement was delivered within each 1-min interval under each schedule. Interobserver agreement (identical recording by independent observers of the number of reinforcer deliveries within intervals) was 100% for all but two sessions (with one disagreement occurring in each).

RESULTS

During the prebaseline condition, the students did not allocate their behavior in patterns predicted by the schedules until timers signaling the VI intervals were made available. Thyme did demonstrate time-allocation matching within the first 18 sessions, but the gradual increase in responding to the richer schedule culminated in exclusive responding on the richer schedule. Matching was immediately reestablished upon introduction of the timers. Although Ali's responding during the first 10 sessions also favored the richer schedule, the introduction of timers at that point quickly resulted in near-matching. Kate responded exclusively to the leaner schedule during the first session and thereafter distributed her behavior nearly equally between the two sets of problems. The introduction of timers had only a minimal effect on this pattern until the 13th session, after which near-matching occurred.

The results of the subsequent experimental phases are displayed in Figure 1, which shows the extent of time-allocation matching across equal- and un-

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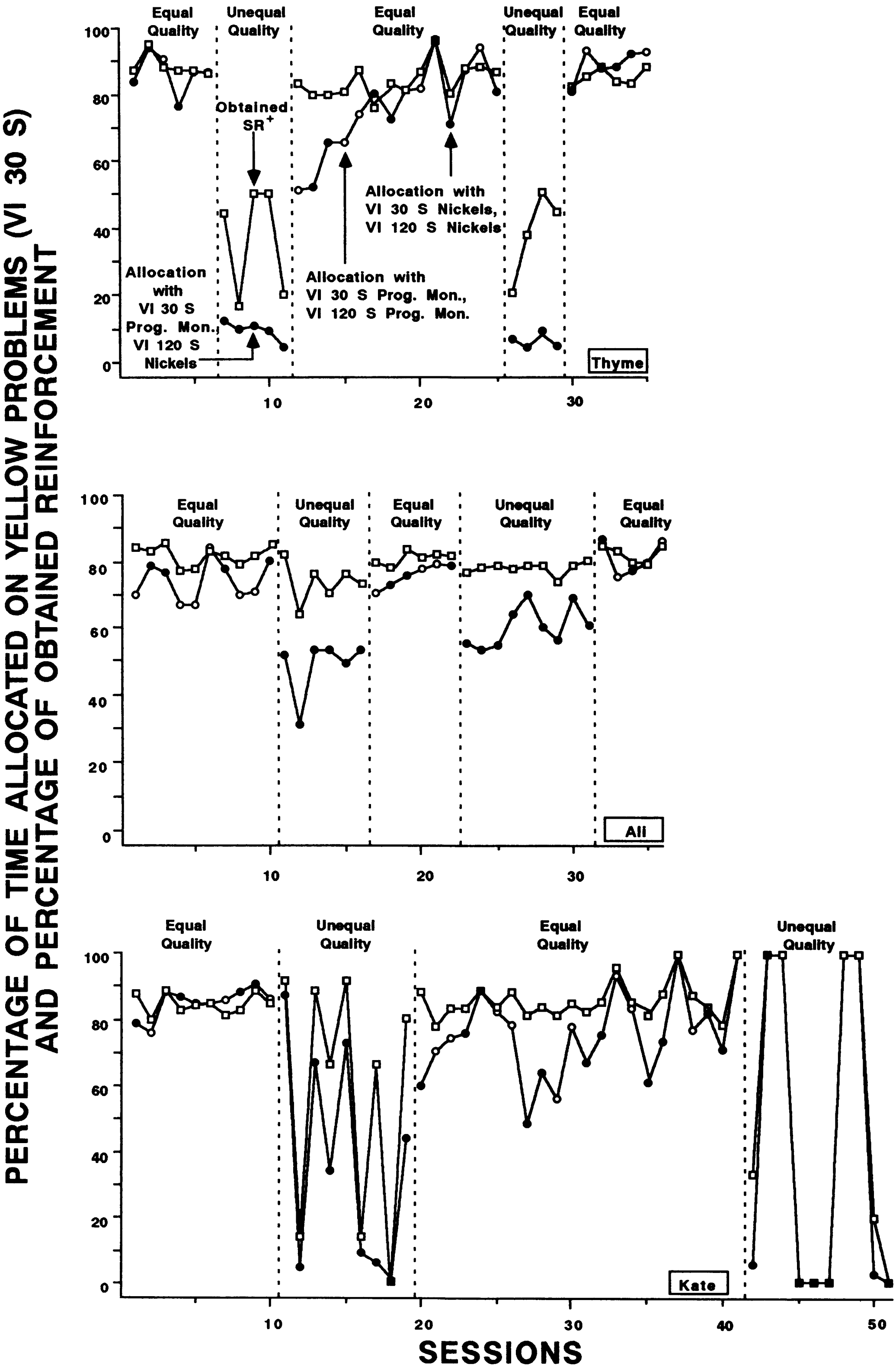
Figure 1. Percentages of time allocated (circles) and obtained reinforcement (squares) on yellow-card problems across equal- and unequal-quality reinforcer conditions for Thyme, Ali, and Kate. (Within the equal-quality reinforcer conditions, closed and open circles represent time allocation when high-quality and low-quality reinforcers were used, respectively.)


PERCENTAGE OF TIME ALLOCATED ON YELLOW PROBLEMS (VI 30 S)
AND PERCENTAGE OF OBTAINED REINFORCEMENT
Equal Quality
Unequal Quality
Equal Quality
Unequal Quality
Equal Quality
Obtained SR+
Allocation with VI 30 S Prog. Mon., VI 120 S Nickels
Allocation with VI 30 S Nickels, VI 120 S Nickels
Allocation with VI 30 S Prog. Mon., VI 120 S Prog. Mon.
Thyme
All
Kate
0
20
40
60
80
100
10
20
30
40
50
SESSIONS

equal-quality reinforcer conditions for Thyme, Ali, and Kate. These data portray the relationship between the percentage of time engaged in responding to the VI 30-s reinforcement schedule and the percentage of obtained reinforcement on that schedule. The former represent $T1/T1 + T2$ (where $T1$ and $T2$ reflect the total amount of time spent on the task alternative subject to the VI 30-s and VI 120-s schedules, respectively), and the latter represent $r1/r1 + r2$ (where $r1$ and $r2$ represent the obtained rates of reinforcement on those alternatives).

The data for Thyme show near-matching (i.e., close correspondence between the percentage of time allocation and obtained reinforcement) when reinforcer quality was equal across the concurrent schedules. The mean difference between the percentage of time allocation and obtained reinforcement was 3.1% (range, 0.1% to 10.8%). During the next condition when the low-quality reinforcer was used on the richer VI 30-s schedule (and vice versa), the percentage of time allocation on that schedule decreased substantially, and the difference between the percentage of time allocation and obtained reinforcement increased (M = 26.9%; range, 6.7% to 40.7%). Upon reinstatement of the equal-quality reinforcer condition, the percentage of time allocation on the VI 30-s schedule gradually recovered to the levels observed in the initial condition, corresponding closely to the percentage of obtained reinforcement. A reversal to the unequal-quality reinforcer condition again resulted in an immediate and substantial reduction in time allocation to the VI 30-s schedule and in the correspondence to the percentage of obtained reinforcement (mean difference = 32.4%). Matching was quickly reestablished in the final equal-quality reinforcer condition; the mean difference between the percentage of time allocation and obtained reinforcement was 4.6%.

A similar pattern of responding was observed for Ali. Slight undermatching occurred during the first equal-quality reinforcer condition, somewhat more so during sessions in which the low-quality reinforcer (program money) was used. That is, the proportion of time she allocated to the yellow cards was slightly less than the proportion of reinforcement she obtained from the richer schedule. The mean difference between time allocation and obtained reinforcement was 7.7% (range, 3.7% to 14.2%). During the unequal-quality reinforcer condition, undermatching was considerably more pronounced, with a mean difference between time allocation and obtained reinforcement of 25.3% (range, 17.2% to 33.2%). When reinforcer quality was again held constant across the concurrent schedules, time allocation corresponded closely to obtained reinforcement (mean difference = 5.3%; range, 2.8% to 9.4%). Upon reinstatement of the unequal-quality reinforcer condition, a bias toward the preferred reinforcer was again evident, although to a lesser extent than in the previous unequal-quality reinforcer phase (mean difference = 17.6%; range, 8.7% to 25.1%). The final equal-quality reinforcer phase produced a recovery of matching (mean difference = 2.8%; range, 0% to 7.6%).

Kate also demonstrated consistent near-matching during the equal-quality reinforcer condition (mean difference = 3.1%). During the unequal-quality reinforcer condition, there was less correspondence between time allocation and obtained reinforcement (mean difference = 21%), but unlike Thyme and Ali, her responding was highly variable. Subsequent reversals produced patterns of responding similar to those in the previous equal- and unequal-quality reinforcer conditions, respectively, although the variability in the second unequal-quality reinforcer conditions was more extreme.

For all 3 students, the percentage of correctly completed problems on the VI 30-s schedule (i.e., the number of yellow-card problems completed divided by the total number of problems completed) closely paralleled the data on time allocation. That is, the results were similar in terms of the relationship of both response rate and time allocation to obtained reinforcement for the respective response alternatives. Incorrect responses rarely occurred (range, 0 to 4) and were fairly evenly distributed across the two sets of problems.

DISCUSSION

This study provides additional evidence that the matching law can account for allocation of socially relevant behavior on concurrent VI VI schedules of reinforcement (Conger & Killeen, 1974). The results also show that the capacity of the matching law to predict human behavior is conditional on reinforcers of equal quality and the subject's discrimination of the properties of VI schedules of reinforcement (Fuqua, 1984).

With equal-quality reinforcers supplied contingent on correctly completed arithmetic problems, the behavior of all 3 students was generally sensitive to the rate at which reinforcers were delivered according to the concurrent VI VI schedules. The schedules arranged four times more nickels or program money for problems on the yellow cards. Under these conditions, matching consisted of jointly allocating and deriving 80% of the time and reinforcers to yellow-card problems and 20% to problems on the green cards. In Thyme's first and third phases with equal-quality reinforcers, she tended to spend approximately 80% of her time with problems on the richer schedule (M = 80.6%), and the match between time allocation and obtained reinforcement was quite close. A similar pattern was evident in Kate's first phase in this condition (M = 84.9%). However, in Ali's first and third phases and Kate's third phase of equal-quality reinforcers, there was a distinct pattern of undermatching (Baum, 1974). That is, these subjects allocated proportionally less time to the yellow cards than the amount of reinforcement they derived from the richer schedule. Although a departure from matching, these results are consistent with the commonly reported finding of basic research on choice under VI schedules that choice proportions are somewhat lower than relative rates of reinforcement associated with the two alternatives (de Villiers, 1977; Lowe & Horne, 1985; Pierce & Epling, 1983). Otherwise, subjects in the present study matched time allocation and obtained reinforcement near 80% with the yellow-card problems.

It should be noted that these findings demonstrate matching as a phenomenon, or outcome, rather than as an operative mechanism, or process, of choice. With our experimental arrangement of concurrent VI VI schedules, maximization (which asserts that behavior is distributed between two alternatives in such a way that overall reinforcement is maximized) and matching accounts both predict the same distributions of behavior. These results are also consistent with melioration, in which behavior shifts toward alternatives yielding higher local rates of reinforcement, as a process that leads to matching (Vaughan, 1981).

Changeover-delay (COD) and limited-hold procedures are often used in matching research to encourage patterns of alternating among response options that enhance sensitivity to scheduled rates of reinforcement. Fuqua (1984) questioned the extent to which such procedures parallel conditions prevalent in natural human environments. He argued that, without these parallels, matching relations obtained on COD and/or limited-hold procedures may not predict allocation patterns of human behavior in applied settings. In response to these concerns, we avoided the use of a COD or limited hold to establish matching in the present study. However, we found that, during prebaseline, Thyme's allocation eventually became exclusive on the richer schedule, Ali showed undermatching with approximately 70% of her time allocated to the yellow cards, and Kate distributed her behavior nearly equally between the two stacks of arithmetic problems. The prebaseline response patterns for Thyme and Kate in particular appeared to indicate that these students did not discriminate the critical features of VI reinforcement schedules. Thus, to facilitate this discrimination, we permitted the subjects to hear the signaling of the VI intervals through the use of countdown timers set by the experimenter. This practice, which nonverbally described the nature of VI schedules to subjects, was discontinued during the remaining experimental phases, when students allocated their behavior in patterns predicted by the schedules. Why some people may have difficulty under some conditions responding to features of VI reinforcement should be the focus of future research. However, until then, we believe this poses a significant obstacle to direct translations of the matching law to natural human settings.

Perhaps the most important finding of this study was the biasing effects that unequal-quality reinforcers have on the matching relation (i.e., a constant proportional preference for one of the two alternatives that exceeds the preference required by matching). In each case, concurrently arranging nickels on the VI 120-s schedule and program money on the VI 30-s schedule resulted in marked departures from the allocation patterns obtained when either nickels or program money was assigned concurrently to both schedules. Thyme showed a strong preference for nickels over program money that overrode the effects of unequal schedules of reinforcement. Despite the four-to-one ratio of reinforcement rates that favored yellow-card problems, Thyme spent over 90% of her time on the green cards, yielding comparatively low-rate reinforcement but the maximum number of nickels available.

Ali's preference for nickels was also consistent, but occurred to a lesser degree than Thyme's. She allocated between 30% and 70% of her time to the leaner schedule associated with the high-quality reinforcer. Ali's results suggest an interaction between reinforcer rate and reinforcer quality. Because reinforcer quality did not completely override the effects of reinforcer rate for Ali, we can speculate that by holding the reinforcer quality differential constant, allocation patterns may have been different at various rate-of-reinforcement ratios (i.e., a parametric analysis of 5:1, 4:1, 3:1, and 2:1 ratios). Indeed, the extent of departures from matching that occur with various reinforcing stimuli, and the compensatory differential in relative rate of reinforcement required for matching to be restored, might be used as a metric of the potency of reinforcers.

Finally, Kate's response to choice with unequal-quality reinforcers was extremely variable. In contrast to the equal-quality conditions in which her responding usually yielded the maximum number of (the same) reinforcers on both schedules, her allocation during the unequal-quality conditions typically ensured receipt of the maximum number of reinforcers on only one or the other schedule (either nickels or program money) on an alternating basis. Thus, although her sensitivity to rate of reinforcement was disrupted, she differed from Thyme and Ali in that her intersession allocation did not consistently favor the same reinforcer. Indifference between the reinforcers associated with the two alternatives is unlikely, because this would suggest a condition functionally equivalent to the equal-quality condition and, thus, allocation would be controlled by rate of reinforcement (matching). Although it is possible that her pattern of responding signified dynamic (rather than neutral) equilibrium, Kate's verbal behavior (frequent complaints regarding nickels being available only on the leaner schedule) does not support that interpretation. We speculate that the experimental arrangements in this (relative to the other) condition did not allow sufficiently powerful or frequent reinforcement to maintain a systematic or complex pattern of responding.

In conclusion, this study provides provisional support for the applicability of matching theory to applied work and identifies some limits to its direct translation to natural human environments. Overall, we are encouraged by these results. The similarities between the findings of basic matching research and those reported in this study are greater than their differences (cf. Davison & McCarthy, 1988). Both show that (a) time allocated to concurrent behaviors is approximately proportional to obtained reinforcement, (b) additional procedures are sometimes necessary to establish sensitivity to the features of VI scheduled reinforcement, and (c) unequal-quality reinforcers can produce biased responding in favor of the high-quality reinforcer that alters the effects produced by rate of reinforcement alone.

Complex natural human environments contain variables in addition to reinforcer rate and reinforcer quality that are likely to affect how individuals choose among available options. Again, basic research has identified some factors that applied researchers may begin to investigate, including response effort (Hunter & Davison, 1982), reinforcer delay (Chung & Herrnstein, 1967), reinforcer amount and duration (Davison & McCarthy, 1988), and various combinations of types of concurrent schedules. Whether results of applied investigations replicate basic research findings directly seems less important to us than the conceptual framework and methodology that basic matching research offers applied behavior analysts for studying choice.

We hope the practical benefits of continuing this line of research will be to identify the most influential variables that affect allocation of human behavior in applied contexts and to develop technologies for promoting choices of adaptive repertoires.

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Received July 3, 1991
Initial editorial decision September 5, 1991
Revision received January 13, 1992
Final acceptance June 2, 1992
Action Editor, David Wacker