Human Time Allocation in Time-based Analog of Concurrent Interval-ratio Schedules

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Six undergraduates participated in concurrent-choice experiment with monetary reinforcers. Each subject was exposed to a time-based analog of concurrent variable-interval variable-ratio schedule with equal time interval values. The time-based analog of variable-interval schedule arranged reinforcers throughout the session, and delivered them while the schedule was chosen. The time-based analog of variable-ratio schedule arranged and immediately delivered reinforcers only while the schedule was chosen. In the time-based analog of concurrent variable-interval variable-ratio schedule, matching theory predicts increase in time allocated to the former schedule, whereas maximization theory predicts increase in time allocated to the latter schedule. Four of six subjects developed preference for the time-based variable-ratio analog schedule. No subjects developed preference for the time-based variable-interval analog schedule. The results did not support the argument that human choice behavior is governed by matching processes and maximization is derivative of the processes.

KEYWORDS: choice behavior, time allocation, matching, maximizing, adult humans

1. Introduction

Choice is a pervasive and important aspect of organism's behavior. Many explanations of choice have been suggested and there is debate as to what is the fundamental process of choice. Explanations of choice can be classified under two general theories. One is matching theory (e.g., Herrnstein, 1970). Matching theory states that individuals allocate time among alternatives in order to match relative time spent to relative values or utilities of the alternatives. The other is maximization theory (e.g., Kagel, Battalio and Green, 1995; Rachlin, Battalio, Kagel and Green, 1981). Maximization theory states that individuals allocate time among alternatives in order to maximize overall value or utility.

To test two theories empirically, it is necessary to assume that utility increases as rate or density of reinforcement increases, when other variables are constant. Rate of reinforcement is defined as amount of obtained reinforcers (goods in economic terms) per unit time. On this assumption, we can devise situations where maximization theory and matching theory make different predictions.

Herrnstein and Heyman (1979) argued that a concurrent variable-interval (VI) variable-ratio (VR) schedule, where a VI schedule and a VR schedule operate concurrently, could separate the predictions between maximization and matching. In the concurrent VI VR schedule, a subject can choose between responding on the VI schedule and responding on the VR schedule. The VI schedule delivers a reinforcer for the first response that occurs after some time has elapsed since the arrangement (or delivery) of the preceding reinforcer, and the time varies from one reinforcer to the next. In the VR schedule, no response during the interval is effective in earning reinforcers. The VR schedule delivers a reinforcer for the last of a specified number of responses, and the number varies from one reinforcer to the next. Every response on the VR schedule advances this schedule and is effective in earning reinforcers. Therefore, in the concurrent VI VR schedule, maximization of reinforcement rate requires that subjects spend most of their time responding on the VR schedule and switch to the VI schedule occasionally to collect the reinforcers arranged by the VI schedule. Herrnstein and Heyman investigated pigeons' choice using concurrent VI VR schedules, and found that time allocations of all four pigeons were close to matching, despite the fact that this considerably reduced the overall rate of reinforcement. They concluded that this result provides decisive evidence against maximization theory and maximization is a derivative phenomenon of matching processes.

Several authors (e.g., Green, Rachlin and Hanson, 1983; Kagel et al., 1995; Rachlin et al., 1981) objected against this conclusion. They pointed out that response requirements were not symmetrical in the concurrent VI VR schedules. VR schedules always require responses to arrange reinforcers. VI schedules, however, do not require any response during the intervals. Therefore, VI schedules provide more "leisure" (defined behavior except for specified responses) than VR schedules. Rachlin et al. (1981) have shown that the results of Herrnstein and Heyman are compatible with maximization theory if the value of "leisure" is taken account. The pigeons may have preferred the VI schedule because it provided more "leisure".

In order to eliminate the effects of asymmetrical response requirements, DeCarlo (1985) devised time-based

analogs of concurrent VI VR schedules. In his experiment, four pigeons were offered choices between spending time on a time-based analog of VI schedule and spending time on a time-based analog of VR schedule. Subjects could alternate schedules by responding on a changeover key. The time-based analog of VI schedule, like a standard VI schedule, arranged reinforcers after intervals of variable duration, independently of subject's choice. But the time-based VI schedule did not require any response (except a changeover response) for delivering the arranged reinforcers. If the schedule was chosen, the arranged reinforcers were delivered immediately. If the schedule was not chosen, the arranged reinforcers were held until the schedule was chosen. The time-based analog of VR schedule arranged and delivered reinforcers after intervals of variable duration only while the schedule was chosen. Consequently, the obtained reinforcers were in direct ratio to the time spent on the schedule. The time-based VR schedule also did not require any response for reinforcers. Therefore, response requirements were symmetrical in the time-based analog of concurrent VI VR schedule. However, this schedule retained the essential features of standard concurrent VI VR schedule. In DeCarlo's experiment, pigeons showed only small bias from matching towards the time-based VR analog schedule. It was too small to maximize overall reinforcement rate. Boelens, Kop, Nagel and Slangen (1986), and Heyman and Herrnstein (1986) also obtained similar results.

The question that whether the results obtained with pigeons are applicable to humans is interesting and theoretically important because maximization of utility is a widely accepted fundamental assumption in the field of economics. Savastano and Fantino (1994) conducted the only previous study of human choice in time-based analogs of concurrent VI VR schedules. Their analysis was, like previous studies with pigeons, based on the difference between the degree of preference measured at "steady-state" and the degree of preference predicted by maximization. They concluded that reinforcement maximization did not control human performance. However, there are some problems in their analysis. First, the number of sessions in each reinforcement schedule condition was relatively few compared with those typical in animal experiments. It is doubtful whether "steady-state" preferences measured by Savastano and Fantino were true steady-state preferences. Second, Savastano and Fantino employed a changeover-delay (COD) to make distinction between alternatives clear. The COD specified that the minimum time during which no reinforcers were delivered since each changeover. But the COD did not specify actual delay of reinforcement. Actual delay was dependent on the subjects' behavior to some degree. This made the quantitative prediction of maximization unclear. Third, the time-based analog of VI schedule Savastano and Fantino used stopped arranging reinforcers after arrangement of a reinforcer until the reinforcer was delivered. This also complicated the quantitative prediction of maximization.

The present study examined human choice behavior in the situation where maximization and matching make different predictions. A within-subject research design was used; that is, each subject's behavior was analyzed individually. Most studies of reinforcement used within-subject research designs because repeated (or prolonged) exposure to reinforcement and repeated measurement of behavior are indispensable for analysis of the effect of reinforcement. Furthermore, within-subject research designs can identify general principles applicable to the behavior of individuals. This is a great advantage over between-group research designs, which are used to identify average effect. In within-subject research designs, generality of principles are tested by replications across subjects. For this purpose, six subjects were used in the present experiment.

Some attempts were made in the present experiment to clarify the difference between the prediction of matching and the prediction of maximization. First, qualitative analysis, which is vulnerable to uncontrolled factors, was avoided. Instead of examining the degree of preference in steady-state, the change of preference in transition was measured and development of preference was examined. Second, only a concurrent schedule consist of a time-based analog of VI schedule and a time-based analog of VR schedule with equal time interval was used. In this concurrent schedule, any time spent on the time-based VR analog schedule makes the time-based VI analog schedule deliver reinforcers more frequently than the time-based VR analog schedule, because the time-based VI analog schedule can arrange reinforcers while the time-based VR analog schedule is chosen. Consequently, a subject in the concurrent schedule has to increase time spent on the VI schedule in order to match relative time spent to relative reinforcement rate. But overall reinforcement rate decreases as the subject does so. Matching theory predicts development of preference for the time-based VI analog schedule, whereas maximization theory predicts development of preference for the time-based VR analog schedule. Third, in order to minimize the influence of pattern or number of changeovers on overall rate of reinforcement, the time-based analog of VI schedule used in this experiment arranged reinforcers continuously and no COD was included.

2. Method

2.1 Subjects

Four female (S1, S2, S4 and S6) and two male (S3 and S5) undergraduates served as subjects.

2.2 Apparatus

Sessions were conducted in a small room (220 cm high, 130 cm long and 260 cm deep). Subjects were seated at

a desk in front of a color monitor (EPSON, PC-286CD). An aluminum box (10 cm wide, 7.5 cm long and 5 cm high) with a blue button (2.5 cm in diameter) was mounted on the desk. The button required a minimum force of approximately 2 N to operate. Presentation of experimental events and data collection were controlled by a microcomputer (EPSON, PC-286V) with a timerboard (JAC, TIMERBOARD II).

2.3 Procedure

Upon entering the experimental room, each subject was given an instruction sheet that stated the following:

The number displayed in the middle of the screen indicates points you have acquired. At the end of the experiment, you will be given appropriate amount of money for the points displayed. Each point is worth one yen. The points will change automatically while the screen is green or red. You can freely choice either situation by pressing the blue button on the desk. The length of experiment is 30 minutes. Please don't rise from your seat until the screen tells you the end of experiment. Please don't touch the body of computer, any switches on the keyboard, and any cords.

A copy of the instruction remained available on the subject's desk throughout the experiment.

Each subject was then exposed to a time-based analog of concurrent VI 15-sec VR 15-sec schedule. The time-based analog of VR 15-sec schedule arranged reinforcers at 15-sec intervals on average only while the schedule was chosen, and the arranged reinforcers were delivered immediately. The time-based analog of VI 15-sec schedule, on the other hand, arranged reinforcers at 15-sec intervals on average throughout the session. But the arranged reinforcers were delivered only while the time-based VI analog schedule was chosen. All reinforcers arranged while the time-based VR analog schedule was chosen were held until the subject chose the time-based VI analog schedule. Both schedules consisted of seven intervals that were approximately exponentially distributed (Fleshler and Hoffman, 1962). In order to minimize the influence of pattern or number of changeovers on overall rate of reinforcement, the VI analog schedule operated continuously and no changeover delay (COD) was employed. Thus, no arranged reinforcer was canceled except by the end of the session.

Which schedule was chosen was signaled by the monitor screen, lighted either red or green. For S1, S2 and S3, the VR analog schedule was correlated with the red throughout the experiment, and the VI analog schedule was correlated with the green. The correlation between schedules and colors was reversed for S4, S5 and S6.

Points exchangeable for money served as reinforcers. Each reinforcement consisted of the addition of one point to the counter in the middle of the monitor screen and was briefly signaled by an audible tone. At the each end of session, total points earned were exchanged for money.

Each subject participated two sessions, one session per day. At the beginning of each session, the monitor screen was black. Subject's first press started a session timer and turned the monitor screen red or green, with equal probability. Each subsequent press had the effect of switching the schedule of reinforcement and the schedule-correlated color of monitor screen. Each session terminated after 30 min, whereupon the monitor screen turned black.

3. Results

All analysis was conducted by dividing the data during the two 30-min sessions into twelve five-min blocks for the purpose of examining changes of the data.

Figure 1 presents the change of preference. The filled circle shows the proportion of time spent on the VR analog schedule during each five-min block for each subject. Spearman's rank correlation coefficient between the blocks and the proportions of time spent on the time-based VR analog schedule was computed for each subject as a measure of development of preference, and is shown in the upper left quadrant of each graph. High positive correlations were obtained for four subjects (S1, S2, S4 and S5), indicating that preference for the time-based VR analog schedule developed in long run. Inspection of the graphs revealed the preference started developing in Day 2. The significance probability of the coefficient was assessed with two-tailed test ($N = 12$) tentatively, though the assumption of random sampling or random assignment was not met in the present experiment. P -value was .051 for S1, .009 for S2, .812 for S3, .000 for S4, .009 for S5 and .983 for S6, respectively. The test revealed that three of six subjects increased the proportion of time spent on the time-based VR analog schedule significantly ($p < .05$).

Figure 1 also presents the change of deviation from matching. The open circle in Figure 1 shows the proportion of reinforcers (i.e. points) delivered by the time-based VR analog schedule. The difference between the proportion of time spent on the time-based VR analog schedule and the proportion of reinforcers delivered by this schedule is just the deviation from matching. The figure indicates that development of preference for the time-based VR analog schedule simultaneously made deviation from matching larger and none of the subjects reduced deviation from matching.

Figure 2 shows the overall reinforcement rate during each five-min block for each subject. Spearman's rank

Fig. 1 Proportions of time spent on the VR analog schedule and proportions of reinforcers obtained there as a function of five-min blocks. Spearman's rank correlation coefficients between blocks and proportions of time are shown in the upper left quadrant of each graph as indices of trends of the latter.

correlation coefficient between the blocks and the overall reinforcement rate was computed for each subject as a measure of change of overall reinforcement rate, and is shown in the upper left quadrant of each graph. High positive correlations were obtained for two subjects (S2 and S4), and low positive correlations were obtained two subjects (S1 and S5). The results were similar to those of the proportion of time, though the trend is relatively unclear because variable schedules were used. Overall reinforcement rate generally increased as proportion of time spent on the time-based VR analog schedule increased. The significance probability of the coefficient was assessed with two-tailed test ($N = 12$) tentatively. P -value was .301 for S1, .019 for S2, .896 for S3, .018 for S4, .298 for S5 and .862 for S6, respectively. The test revealed that two of six subjects increased overall reinforcement rate significantly ($p < .05$).

4. Discussion

The results of this experiment were entirely different from those of previous experiments with pigeons. In the experiments with pigeons, all subjects showed preference for the time-based VI analog schedule when the time-based VI analog schedule and the time-based VR analog schedule arranged reinforcers at equal rates (Boelens et al., 1986; DeCarlo, 1985; Heyman and Herrnstein, 1986). By contrast, none of the adult human subjects in the present experiment developed preference for the time-based VI analog schedule. More significant is the fact that some of them developed preference for the time-based VR analog schedule. That is, some subjects increased overall reinforcement rate and simultaneously increased the deviation from matching. The present results did not support the argument that matching is the fundamental processes of human choice and maximization is the

Fig. 2 Overall reinforcements per minute as a function of five-min blocks. Spearman's rank correlation coefficients between blocks and overall reinforcement rates are shown in the upper left quadrant of each graph as indices of trends of the latter.

derivative of matching processes.

This finding is consistent with the results of experiments using "self-control" situations, where subjects choose between small but immediate reinforcers and large but delayed reinforcers. In the situations, adult humans, unlike pigeons, showed tendency to maximize overall reinforcement rate (e.g., Flora and Pavlik, 1992; Logue, King, Chavarro and Volpe, 1990; Logue, Peña-Correal, Rodriguez and Kabela, 1986).

It is not evident whether the difference between the present results with humans and the previous results with animals is due to the difference of species. The type of reinforcers can also account for the difference of the results. The present experiment, like most other human experiments, used points exchangeable with money as reinforcers, whereas most animal experiments used foods as reinforcers. Some studies of "self-control" reported that some adult humans could not show "self-control", that is, failed to maximize overall reinforcement rate when primary reinforcers (food or video game playing) were used (e.g., Logue and King, 1991; Millar and Navarick, 1984).

Although the present results are apparently inconsistent with matching, this does not mean that only maximization process control human choice behavior and matching process never. It may be appropriate to say that both maximization and matching processes controlled choice behavior and the effect of the former was stronger in the situation employed in the present experiment. If so, further investigations are required to identify situations where humans can maximize overall utilities.

It should be noted that whether humans develop preference predicted maximization is one thing and whether humans show preference predicted by maximization at a point of time is another. The present results do not mean that human behavior is always optimal. Even the subjects who developed preference predicted by maxi-

zation could not achieve perfect maximization within the period of this experiment. This suggests that one possible necessary condition for optimal behavior is stability of reinforcement contingency.

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