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15 Rational Human Behavior in Schedules of Reinforcement

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Is organisms' behavior rational? Rationality has been examined in operant conditioning studies of response rate differences under variable-ratio (VR) and variable-interval (VI) schedules. The response rate under VR schedules is usually higher than that under VI schedules, when both schedules provide the same rate of reinforcement. This finding was originally reported by Ferster and Skinner (1957) in pigeons and was later replicated in rats (Kintsch, 1965), monkeys (Silberberg, Warren-Boulton, & Asano, 1988), and humans (Matthews, Shimoff, Catania, & Sagvolden, 1977).

How this difference to be explained? Rational explanation, also known as molar theory, attributes the VR-VI response rate discrepancy to the differences in the relationship between response rates and reinforcement that each type of schedule engenders. Increases in response rate during VR schedules are correlated with increases in reinforcement rates, whereas no such correlation is observed for VI schedules. If response emission is controlled by the magnitude of this correlation, subjects should respond faster under VR schedules than under VI schedules (Baum, 1981). This molar theory is said to be rational because it considers the global relationships between response (rates) and reinforcement (rates).

An alternative non-rational explanation, called molecular theory, focuses on reinforced interresponse times (IRTs). During VI schedules, the

probability of reinforcement is an increasing and bounded function of IRT duration, whereas during VR schedules the probability of reinforcement is independent of IRT duration. If response emission is controlled by this relationship, the simplest prediction would be that longer IRTs should be more frequent under VI schedules than under VR schedules—which would mean lower response rates under VI schedules (Morse, 1966). This molecular theory is non-rational in that the theory focuses only on the local relationships between response and reinforcement.

Studies of animals to date favor the molecular theory. Both Cole (1999), Reed, Soh, Hildebrandt, DeJongh, and Shek (2000), and Reed, Hildebrandt, DeJongh, and Soh (2003) showed that rats are not sensitive to molar variables. In these experiments, response rates under a VI plus linear feedback (VI+) schedule, which has both VI-like molecular properties and VR-like molar properties, were approximately the same as those under a standard VI schedule. In addition, Peele, Casey, and Silberberg (1984) and Tanno and Sakagami (2008) showed that in pigeons and rats, the manipulation of reinforced IRTs can cause a VR-VI response rate difference. These researchers examined tandem VI differential reinforcement of high rate (DRH) and regulated probability interval (RPI) schedules—both of which have VR-like molecular properties and VI-like molar properties. They showed that response rates under tandem VI DRH and RPI schedules were similar to those observed under a VR schedule. VR-VI rate differences appear to be shaped non-rationally, at least in animals.

Studies of humans, however, have produced conflicting results. Human performance under tandem VI DRH schedules is similar to that of animals. Reed (2001, 2003) reported that response rates and causality judgments—the degree of perceived causality between response and reinforcement rated on a scale from 0 to 100—were higher under a tandem VI DRH schedule than under a VI schedule. On the other hand, the nature of human performance under VI+ schedules supports the molar theory. McDowell and Wixted (1986) and Reed (2007) showed that response rates under VI+ schedules were higher than those under VI schedules.

Why have these conflicting results been obtained? One hypothesis is that humans are sensitive to both molecular and molar variables. The purpose of the present experiment was to demonstrate humans' sensitivity

to both molecular and molar variables. Participants were exposed to VR, VI and RPI schedules. If humans are sensitive to molar variables, response rate and contingency judgments under an RPI schedule should approximate those observed under a VI schedule. In addition, our participants rated the degree to which they noticed the molecular properties of the VI schedule and the molar properties of all three schedules. If participants are sensitive to the VI schedule's molecular properties, high rating scores for this awareness should be obtained.

Method

Participants

Twenty-one participants (3 male and 18 female) were recruited on and around the Mita campus of Keio University. Participant ages ranged from 19 to 28 (mean = 21.14).

Device

An IBM laptop computer with a mouse was placed on a table in a quiet room. The computer controlled all experimental events and recorded all data by means of Visual Basic 2005 software.

Procedure

Initially, the participants were exposed to a VR 9 schedule, and then to inter-reinforcement interval (IRI) yoked VI and RPI schedules. These three schedules were displayed as *Area A*, *Area B*, and *Area C* on the computer screen. The order of the VI and RPI schedules was counterbalanced across participants. Each of the schedules lasted for four minutes, and they were presented two times each in a strict order (Phases 1 and 2). After each schedule was finished, each participant judged perceived causality between responses and reinforcement on a rating scale of 0 to 100.

Under the RPI schedule, the *n*th response was reinforced according to the following equation:

$$P_{rft}\,(n) = R_{VR}\; t / m\;, \qquad (1)$$

where P_{rft} (n) is the probability of reinforcement of the nth response, RVR is the average reinforcement rate during the recent VR 9 schedule for each participant, t is the total duration from the ($n - 1 - m$) IRT to the ($n - 1$) IRT, and m is the IRT memory size. IRT memory size was set at 30. Therefore, *t/m* was equal to the average duration of the last 53 IRTs with a lag of one. The definition of t meant that $P_{rft}\,(n)$ was independent of the IRT of the nth response, and should therefore result in RPI reinforcer rates that were the same as those for an RVR schedule.

A cover story similar to that used by Reed (2001, 2003) was provided to participants at the start of the experiment. The cover story was as follows: (1) Initially participants have 100$ in funds; (1) the job of the participants was to increase their funds and to accurately report on the effectiveness of their investments under three different economies; (3) each mouse click on the "investment" button (displayed on the screen) corresponds to one investment; (4) Each investment required 1$, and participants may or may not receive $100 in return.

At the end of the experiment, each participant was informed about the molecular properties of the VI schedule and the molar properties of all three schedules, and then rated the degree to which they noticed these properties on a scale from 0 to 10.

Results

One participant showed an excessively low response rate (one response per minute), so their data was excluded from the following analyses. The top panel of Figure 1 shows median response (investment) rates. In Phase 1, response rates under the RPI schedule were higher than those under the VI schedule, but this difference disappeared in Phase 2. Response rates under the VR schedule were the highest amongst the three schedules, in both Phase 1 and 2. These observations were partially corroborated by an ANOVA, with schedule (VR, VI, and RPI) and phase as within-subjects factors. The AVOVA revealed a statistically significant main effect of schedule, F (2, 38) = 3.07, $p < 0.05$. Tukey's HSD tests conducted on these

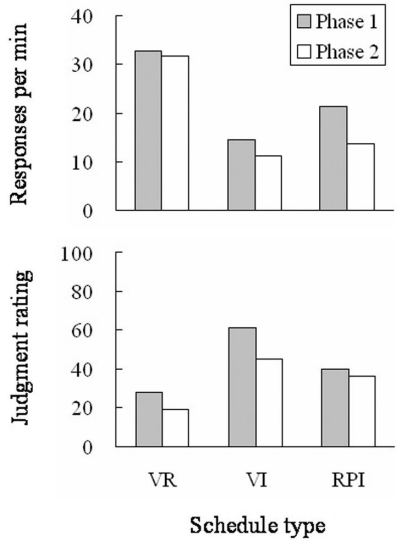

Figure 1. Response rates (top) and contingency judgment ratings (bottom) under three reinforcement schedules in Phases 1 and 2.

data revealed a significant difference between VR and VI schedules.

The bottom panel of Figure 1 shows average causality judgment ratings. Ratings for the VI schedule were higher than those under the VR schedule, and were also higher than those under the RPI schedule. These differences were smaller under Phase 2 than under Phase 1. These observations were confirmed using an ANOVA, with schedule (VR, VI, and RPI) and phase as within-subjects factors. The AVOVA revealed statistically significant main effects of schedule, F (2, 38) = 12.25, $p <$ 0.01, and phase, F (1, 19) = 6.77, $p < 0.01$. Tukey's HSD tests revealed significant differences between the VR and VI and RPI and VI schedules.

Table 1 summarizes reinforcement rates, median duration of reinforced IRTs, and reinforcement probabilities. Reinforcement rates under the three schedules were approximately the same in Phase 2, whereas this was not the case for Phase 1. Median durations of reinforced IRTs under the VI schedule were higher than under the VR schedule, and those under the RPI schedule were similar to those under the VR schedule. The order of reinforcement probabilities from high to low was the VI, followed by the RPI, and lastly the VR schedule.

Table 1. Summary results of present experiment.

Phase	Index	Schedule		
		VR	VI	RPI
1	Reinforcers per min	5.16	4.41	3.42
	Median reinforced IRT (s)	0.98	8.93	1.04
	Reinforcement probability	0.15	0.19	0.15
2	Reinforcers per min	2.75	2.61	2.68
	Median reinforced IRT (s)	0.72	10.10	1.11
	Reinforcement probability	0.10	0.17	0.14

Notes: The values are averages across 20 participants

I calculated the Pearson product-moment correlation coefficient to capture the seeming relationship between causality judgments and reinforcement probability. The coefficient was 0.59, suggestive of a positive relationship between these two variables.

The average rating of the extent to which the molecular properties of the VI schedule were noticed was 6.5, and similar ratings for the molar properties of the VR, VI, and RPI schedules were 1.5, 3, and 2.5 respectively.

Discussion

The results of the present experiment provide evidence that humans are sensitive to both the molecular and molar properties of reinforcement schedules. Response rates were consistent with the molar prediction. Response rates were higher under the VR schedule than the VI schedule, and rates under the RPI schedule approximated those under the VI schedule. The additional finding that the duration of reinforced IRTs under the RPI schedule was similar to those under the VR schedule complemented these results. On the other hand, rating (of the extent to which the molecular and molar properties) data also suggest that participants' performance under the VI schedule was controlled (at least in part) by molecular properties.

The present causality judgment findings can also be considered as

evidence of human rationality. Delta-P, the difference between the probability of an effect-event in the presence and absence of a cause-event (Reed, 2001) can serve as an index of the causal relationship between two events (i.e., reinforcement probability in schedules of reinforcement). The high correlation between reinforcement probability and causality judgments observed here is indicative of human rationality.

Usually, the RPI and tandem VI DRH schedules are considered to have the same molecular and molar properties: VR-like molecular properties and VI-like molar properties. However, Reed (2001, 2003) reported that response rates and contingency judgments under a tandem VI DRH schedule were higher than those under a VI schedule, in contrast to the results for the RPI schedule noted above. This discrepancy may be due to the molecular properties of RPI and tandem VI DRH schedules. In both schedules, the duration of reinforced IRTs will be the same as for a VR schedule. However, in a RPI schedule this occurs because reinforcement probability is independent of IRT duration, whereas in a tandem VI DRH schedule IRTs are similar to reinforced IRTs under a VR schedule, in that they have a high reinforcement probability. This consideration suggests the hypothesis that humans are more sensitive to molecular properties—that is, they show non-rational behavior—when reinforcement probability is dependent upon the duration of IRTs under schedules of reinforcement.

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