7. SYMPOSIUM: PSYCHOLOGICAL RESEARCH USING COMPUTER GAME TECHNOLOGY

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The matching game: Testing for the generality of the matching law

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The matching law suggests that animals will allocate responses as a function of reinforcer availability; that is, if one choice produces more reinforcement, a greater proportion of total responding will be allocated to that choice. Indeed, there tends to be a match between response allocation and proportions of reinforcers delivered, given each of those choices. A computer game that delivers simulated coins of experimenter-selected denominations for responding on either of two keys was developed to test the generality of the matching law. The data suggest that even within a single 10-min session, matching functions may be obtained (although undermatching was the rule in the present results). This program may also be used to test various accounts of the matching law.

The matching law (Herrnstein, 1961) describes a stable relationship between allocation of responses and the resulting distribution of reinforcers when animals are confronted with two or more choices simultaneously. Generally, under such conditions, the proportion of responses allocated to a particular choice will match the proportion of reinforcers obtained on that choice. This finding is so stable across species that the derived proportional relation has been stated in a simple algebraic form:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2},$$

where R_1 and R_2 are the rates of responding on the two choices, and r_1 and r_2 are the corresponding reinforcer rates obtained on the two choices (Herrnstein, 1961).

A typical matching experiment might present two choice keys to a pigeon with separate schedules of reinforcement operating on each key. If the schedules deliver food at, on average, equal frequencies, the pigeon will divide its responses equally across the two alternatives. Generally, these schedules are based on responding after the passage of time (interval schedules) rather than after

a specific number of responses (ratio schedules). If ratio schedules are used, animals will typically respond exclusively on the key with the smallest ratio requirement, thereby eliminating the choice conditions. (This exclusive response pattern also reflects matching, however, in that 100% of the responses will be emitted to the "richest" reinforcement key followed by 100% of the reinforcers being delivered on that key.)

It is perhaps a more realistic case that as an animal works on one alternative, reinforcers are coming available on a second alternative. Frequently, organisms earn reinforcers simply by being in the right place at the right time; obtaining these reinforcers is then a simple matter (Rachlin, Green, & Tormey, 1988). For example, as an animal hunts in one area, additional prey may be coming into a second region. The only serious consideration is how long it takes to move from one hunting ground to another; if travel time is very brief, the animal may switch between the hunting areas frequently, whereas if travel time is long, switching may be infrequent.

In order to simulate these properties of reinforcer choice in the natural environment, matching experiments have typically utilized concurrent interval schedules, with a change-over-delay (COD) contingency imposed when the subject switches responding from one key to the other. This COD requirement prevents the animal from simply alternating between keys. That is, the contingency forces the animal to stay with a particular choice for at least the COD duration before a reinforcer is obtained. Usually, COD requirements are only 1–2 sec

This paper is dedicated to the memory of Richard J. Herrnstein, whose work prompted the programming of this software. Special thanks to Howard Gallup for his support and work on this project. Copies of this paper or the software may be obtained from R. W. Allan, Department of Psychology, Lafayette College, Easton, PA 18042 (e-mail: allanr@lafayette.edu).

in duration, research having shown that these durations are sufficient to prevent animals from alternating rapidly between keys.

Although some matching research has examined human choice (for reviews, see Bradshaw & Szabadi, 1988; Epling & Pierce, 1983; Pierce & Epling, 1995), the great majority of work on matching has used pigeons and rats as subjects (for reviews, see Davison & McCarthy, 1988; Williams, 1988). At least one of the reasons for this relative paucity of research on matching in humans concerns task selection. At a minimum, the task should allow the experimenter to control schedule and COD requirements with sufficient precision to provide an unambiguous interpretation of the human subjects' performance. Such tasks have not been easy to design (e.g., Conger & Killeen, 1974; see also Pierce & Epling, 1995), and some human matching research has obtained results reflecting high levels of undermatching; that is, there has been a tendency for the subject to respond at higher rates than predicted on the choice for which the rate of reinforcement is relatively low (e.g., Navarick & Chellson, 1983; Wurster & Griffiths, 1979). However, undermatching is a result frequently seen even in well-controlled animal research, and its prevalence prompted Baum (1974) to propose a generalized matching law—namely,

$$R_1/R_2 = k(r_1/r_2)^a,$$

in which values for the k parameter may be adjusted to account for a bias toward one response alternative, and values of a may be set to predict undermatching or overmatching (the latter suggesting that response proportions are always lower than predicted by the corresponding, relatively high reinforcer proportions).

This paper presents some data produced by subjects responding on a computer keyboard. The computer program described herein was designed to provide a simple response environment that would allow researchers to control choice conditions with sufficient precision to allow the effects of stimulus and consequential operations to be appropriately assessed (see Herrnstein, Loewenstein, Prelec, & Vaughan, 1993). The program also allows for the collection of a large number of responses over a short period of time, and tends to produce data that support the generalized matching law. Most importantly, the program provides an environment that is flexible. Researchers should be able to examine a number of important issues surrounding choice behavior by adjusting parameters of the program.

METHOD

Subjects

Fifty-seven undergraduates who were enrolled in two sections of an experimental psychology course participated as part of the laboratory requirement for that course. All subjects were treated in accordance with the guidelines of the American Psychological Association.

Apparatus

Ten 20-MHz PC-clone computers with VGA color displays were used to present stimuli, reinforcer-schedule conditions and to col-

lect keystroke and response-time information. A custom software program was written in QuickBasic (Microsoft), and was compiled to run on the 10 computers.

Procedure

The program began by asking the experimenter for a COD value (which applied to switches of responding from either the z or the p key to the alternate key). It followed this by asking the experimenter to enter three parameter values for the schedule operating when the left, or z , key was being pressed. These values were: (1) the random interval (RI) schedule value for z presses; (2) the descent speed for coins delivered contingent on z presses (higher values resulted in slower coin-descent times); and (3) the value of the coins delivered contingent on z presses. The program then asked for a similar set of values for right, or p , keypresses. Following this, it asked for the session duration (in sec), and then for a file name (the subject's data were stored in this file at the end of the session). Finally, the program asked for confirmation of the correct status of the parameter values entered as they appeared on the screen. If the user responded by striking any key other than y , the program repeated each question until the user was satisfied with the values.

The program then cleared the screen and presented the following instructions, designed to be read by the experimental subject:

Your task is to accumulate as much money as possible. At the top of the screen you will see two boxes, each of which can deliver coins. These coins will drop and collect in the boxes at the bottom of the screen. However, you have to respond in order to release the coins. You will have only a limited time in which to collect coins. In addition, you may use only one hand when responding. To release coins from the left box, you must hit the z key; to release coins from the right box, you must hit the p key. Note that coins will not be released for every z or p response, but rather, they will be released periodically. Remember, LEFT- z , RIGHT- p . None of the other keys will be operative. The amount of money you collect will be indicated by counters next to the boxes the coins fall into. Remember, your task is to accumulate as much money as possible, regardless of which box you collect money from. A beep will indicate the end of the session. If you have any questions, talk to the experimenter now! Strike any key to begin. Remember, only one hand!

After a key was pressed, the computer beeped, the screen was cleared, and, in graphics mode, four boxes appeared, two of them centered side by side at the top of the screen, and two centered 11.5 cm directly below the top two boxes. Each box measured 7 × 2.5 cm (width × height), with a 7-mm horizontal gap between adjacent boxes (these values will vary depending on the size of the monitor). The values (in cents) of the coins that were potentially delivered from the boxes at the top of the screen were indicated above each box.

A beep then sounded, and a message that told the subject, "Begin responding to z or p now!" appeared at the center of the screen between the vertically positioned boxes. When the subject responded with either a z or a p keypress, the prompt was removed and the session timer began counting (although session time was not displayed on the screen).

For the remainder of the session, z and p keypresses were reinforced on their separate RI schedules. The RI schedules on each key were arranged as follows: After each sec of the session, two random numbers between 0 and 1 were sampled (one for each key), and each random number was compared with the criterion value for that key. These criteria were determined at the beginning of the session by dividing the RI value for each key into 1. A coin release was made available on that key if the random number sampled from the computer was equal to or less than the criterion value established for that key.

If the subject switched to a key that had a reinforcer available, he or she had to continue responding on that key until the COD was met, at which point the coin was released from the box at the top

of the screen. When released, the coin appeared to fall end over end into the collection box below. The speed of coin descent was constant across all conditions, but could be adjusted by the experimenter.¹

In addition, whenever a key response was made, the time of that response from the beginning of the session was stored (an analysis of that data, however, is not provided in this report). If a coin was produced, the time of reinforcement from the start of the session was also stored. These data were written to disk at the end of the session.

When a coin fell into the collection box, a simulated "clinking" of the coin was presented and the total accumulation (in cents) was indicated next to the collection box. The subject continued to respond to one of the two keys until the session time elapsed. The computer then beeped, and the following message appeared: "This session is over . . . Thank you." Directly below this message was a question: "Do you wish to quit this program? (y/n)." If the subject responded by pressing the *y* key, the program stored the subject's response-time and reinforcer-time data to disk under the file name entered at the beginning of the session. At the end of this data file, the program also wrote the following values to the disk: (1) Number of left (*z*) responses; (2) number of right (*p*) responses; (3) the left RI value; (4) the right RI value; (5) the duration spent responding on the left key; (6) the duration spent responding on the right key; (7) the coin value for the left key; (8) the coin value for the right key; (9) the session duration; (10) the number of reinforcers delivered on the left; (11) the number of reinforcers delivered on the right; (12) the actual number of reinforcers made available (if a subject responded exclusively on one key for long periods, reinforcers may have been "lost" on the other key as the sequential RI intervals elapsed); and (13) the percentage of those reinforcers made available that were actually obtained. From these data it is possible to calculate several commonly derived measures related to the matching law. For example, researchers frequently plot the proportion of responses on one key as a function of the proportion of reinforcers obtained on that key.

Experimental conditions. One group of 14 subjects was exposed to three 10-min concurrent-schedule sessions with a left (*z*) RI value of 15 sec and a right (*p*) RI value of 5 sec. A second group of 15 subjects was exposed to the same conditions, but the RI-schedule values were reversed on the left and right keys. A third group of 15 subjects was exposed to equal RI schedules (7.5 sec on each key).

A fourth group of 9 subjects was exposed to within-subjects conditions in which they first responded on a concurrent RI-15-sec: RI-5-sec schedule for two sessions, followed by two additional sessions with the schedules reversed on the left and right keys.

At the conclusion of the experiment, the subjects were given copies of the experimental data for their use in the laboratory course.

RESULTS

For each subject's performance in each session, the relative rate of responding to the left (*z*) key was plotted as a function of the relative rate of reinforcement delivered for responding on that key. If matching is obtained, data points should fall close to the diagonal (see Figure 1).

Figure 1 plots the data from the first three groups, with their concurrent-schedule values indicated in the legend of that figure. It is clear that when the RI 15-sec schedule was offered on the left key, the subjects tended to respond less to that key (filled circles). All of the subjects in this condition did undermatch; that is, their response proportions tended to be slightly higher on the

Figure 1. Proportion of left- (*z*-) key responses as a function of proportion of reinforcers delivered for responding on that key. Each data point represents the proportion for a single subject. The schedules maintaining subjects' performances are indicated in the legend.

key with the lowest relative rates of reinforcement (in this case, the left key). As predicted by the generalized matching law, however, the data points tend to accumulate in the lower-left corner of the figure.

For the second group, with the RI 5-sec schedule in effect on the left key, relative rates of responding tended to undermatch as well. This can be seen in Figure 1, as all of the data points (filled triangles) are located in the upper left of the figure, but below or close to the diagonal. This suggests that the response proportions on the other (unplotted) right key (with the RI 5-sec schedule in effect) would be located in the lower-left corner but above the diagonal, just as predicted by undermatching. The findings for both of these groups are consistent with previous undermatching results.

The third group, whose RI schedules were equal (RI 7.5 sec on each key), tended to produce response proportions close to 0.5 (filled squares). This is a finding also predicted by the generalized matching law.

Data from the fourth group are depicted in Figure 2. Each plot represents the data from a single session, with individual data points representing the performance of single subjects in that session. In the first column of plots, the subjects' response proportions reflect undermatching; more importantly, from the standpoint of assessing the consistency of results produced with the computer program, there appears to be little, if any, change from one session to the next. However, there is a dramatic shift in response proportions during the first session after the RI-schedule values were switched from one key to the other (Figure 2, second column of plots). All of the subjects' data points moved from the lower left to the upper right of the figure, while maintaining the characteristic

Figure 2. Proportion of left- (z-) key responses as a function of proportion of reinforcers delivered for responding on that key. Each data point represents the proportion for a single subject. The concurrent schedules in effect during each session are indicated as column labels, while session numbers are indicated in the upper-left corner of each plot.

undermatching pattern. Finally, during the second session after the schedule switch, the response proportions appear to be unchanged.

DISCUSSION

The data provide support for the matching law and suggest that even when sessions are quite brief (in this case, 10 min), subjects' responding is very sensitive to reinforcement density. The tendency to undermatch is a result that has been obtained frequently in both animal and human matching research, and suggests that the present data fit nicely with predictions made by the generalized matching law (see Bradshaw & Szabadi, 1988). Indeed, the consistency of session-to-session performance in the within-subjects group suggests that reinforcer-density effects may take substantial and orderly control of behavior in a single session. Taken together, these data sup-

port the validity of the matching law as a good predictive model of individual choice behavior.

In addition, the computer program used in this study is sufficiently flexible that future research questions can be easily asked by modifying some of the program routines. For example, questions concerning such issues as delay-of-reinforcement effects (as reflected in this program by speed of coin descent; see Herrnstein et al., 1993), the effect of three or more response alternatives, and systematic manipulation of the COD requirements (to name just a few) may be carefully confronted using this software or a slightly modified version. Apparently, the contingencies, as presented to the subject on the computer, are robust enough to exert rather dramatic control during very brief sessions. Finally, with all of the data easily collected and analyzed on the computer, this program commends itself as an easy-to-use research and pedagogical tool.

REFERENCES

- BAUM, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, **22**, 231-242.
- BRADSHAW, C. M., & SZABADI, E. (1988). Quantitative analysis of human operant behavior. In G. Davey & C. Cullen (Eds.), *Human operant conditioning and behavior modification* (pp. 225-259). New York: Wiley.
- CONGER, R., & KILLEEN, P. (1974). Use of concurrent operants in small group research. *Pacific Sociological Review*, **17**, 399-416.
- DAVISON, M., & MCCARTHY, D. (1988). *The matching law*. Hillsdale, NJ: Erlbaum.
- EPLING, W. F., & PIERCE, W. D. (1983). Applied behavior analysis: New directions from the laboratory. *Behavior Analyst*, **6**, 27-37.
- HERRNSTEIN, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, **4**, 267-272.
- HERRNSTEIN, R. J., LOEWENSTEIN, G. F., PRELEC, D., & VAUGHAN, W. (1993). Utility maximization and melioration: Internalities in individual choice. *Journal of Behavioral Decision Making*, **6**, 149-185.
- NAVARICK, D. J., & CHELLSON, J. (1983). Matching versus undermatching in the choice behavior of humans. *Behaviour Analysis Letters*, **3**, 325-335.
- PIERCE, W. D., & EPLING, W. F. (1995). *Behavior analysis and learning*. Englewood Cliffs, NJ: Prentice-Hall.
- RACHLIN, H., GREEN, L., & TORMEY, B. (1988). Is there a decisive test between matching and maximization? *Journal of the Experimental Analysis of Behavior*, **50**, 113-123.
- WILLIAMS, B. A. (1988). Reinforcement, choice, and response strength. In R. C. Atkinson, R. J. Herrnstein, G. Lindsey, & R. J. Luce (Eds.), *Stevens' handbook of experimental psychology* (pp. 167-244). New York: Wiley.
- WURSTER, R. M., & GRIFFITHS, R. R. (1979). Human concurrent performances: Variation of reinforcer magnitude and rate of reinforcement. *Psychological Record*, **29**, 341-354.

NOTE

1. Coin descent is also a function of the microprocessor speed; faster microprocessors generate faster coin descent. If the effect of coin descent speed is a factor the experimenter wishes to examine, several pilot sessions should be run in which coin-descent speed is mapped onto the values entered at the start of the program.

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