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Concurrent performance in a three-alternative choice situation: Response allocation in a Rock/Paper/Scissors game☆

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ABSTRACT

Adult human subjects engaged in a simulated Rock/Paper/Scissors game against a computer opponent. The computer opponent's responses were determined by programmed probabilities that differed across 10 blocks of 100 trials each. Response allocation in Experiment 1 was well described by a modified version of the generalized matching equation, with undermatching observed in all subjects. To assess the effects of instructions on response allocation, accurate probability-related information on how the computer was programmed to respond was provided to subjects in Experiment 2. Five of 6 subjects played the counter response of the computer's dominant programmed response near-exclusively (e.g., subjects played paper almost exclusively if the probability of rock was high), resulting in minor overmatching, and higher reinforcement rates relative to Experiment 1. On the whole, the study shows that the generalized matching law provides a good description of complex human choice in a gaming context, and illustrates a promising set of laboratory methods and analytic techniques that capture important features of human choice outside the laboratory.

1. Introduction

The matching law, originally formulated by Herrnstein (1961), states that the proportion of responses on two or more concurrent choice alternatives will match the proportion of reinforcement obtained by each alternative. The original investigation analyzed the allocation of responding of pigeons in an experiment with two concurrently available response-keys programmed such that responses after a variable interval would result in access to grain (independent variable-interval [VI] schedule of reinforcement). The results indicated that the rate of responding on each key closely matched the rate of reinforcement (i.e., grain) obtained on each key. In these terms, response allocation as a function of reinforcement can be expressed as

$$\frac{B_1}{B_2} = \frac{r_1}{r_2}, \quad (1)$$

where B_1 and B_2 are the responses on Alternatives 1 and 2, respectively, and r_1 and r_2 are the reinforcement obtained by those alternatives. This formula, therefore, analyzes one choice alternative and the reinforcement obtained by that choice as a proportion of the total amount of responses and reinforcement.

A *generalized* form of matching (Baum, 1974) can be expressed as:

$$\frac{B_1}{B_2} = k\left(\frac{r_1}{r_2}\right)^a, \quad (2)$$

where the added the parameters k and a reflect bias and sensitivity, respectively. Bias represents preference for one alternative that cannot be accounted for by differences in reinforcement rates; sensitivity is a measure of how changes in reinforcement rates are reflected in changes in behavior.

In addition to scores of studies with nonhuman subjects and food reinforcers (see reviews by Baum, 1979; Davison and McCarthy, 1988; Wearden and Burgess, 1982), the matching law has been applied to human behavior in a variety of settings, including natural environments (e.g., McDowell, 1988), human verbal behavior and communication (e.g., Borrero et al., 2007; Conger and Killeen, 1974; Pierce et al., 1981), problem and appropriate behavior in children and adults (e.g., Borrero and Vollmer, 2002), drug self-administration (e.g., Spiga et al., 2005), and sports game play (e.g., Reed et al., 2006; Romanowich

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et al., 2007; Vollmer and Bourret, 2000), to name just a few.

Across species and settings, the majority of studies on matching involve just two choice alternatives. The few experiments that have used more than two response alternatives suggest that matching provides an excellent description of choice (e.g., Davison and Hunter, 1976; Davison et al., 2007; Elsmore and McBride, 1994; Miller and Loveland, 1974; Pliskoff and Brown, 1976; Prelec and Herrnstein, 1978). For example, Davison and Hunter (1976) investigated choice as a function of reinforcement under VI schedules on an individually available key, as well as two- and three-concurrent schedules. The design of the experiment had several conditions in which the three response keys were illuminated white and each was associated with independently arranged and randomized VI schedules or extinction. For example, in one condition, the VI schedules on Keys 2 and 3 (VI 120 s and VI 60 s, respectively) remained constant while the VI schedule on Key 1 was varied (from extinction to VI 15 s); another condition in which Keys 1 and 2 were VI 60 s and VI 120 s, respectively, and the schedule on Key 3 was varied, and another in which Key 2 was associated with a VI 120 s schedule and Key 3 was extinction and varied Key 1, et cetera. The relative rate of responding and the amount of time in the presence of an alternative were assessed as a function of relative reinforcement obtained by that alternative. The data were well described by the generalized matching law for both the two- and three-concurrent VI schedules and the authors noted that the slopes of the lines within the two- and three-concurrent schedules were not significantly different from one another.

Pliskoff and Brown (1976) investigated three-alternative choice with pigeons using a changeover-key procedure (Findley, 1958). Responses on the right key (schedule key) were reinforced according to one of three possible VI schedules, signaled by differently colored key lights; responses on the left key (changeover key) changed the schedule key. Consistent patterns of matching were observed, usually within the first few sessions, prompting the authors to conclude that matching occurs in a three-concurrent choice context in much the same way as it does in more conventional two-concurrent choice contexts.

Miller and Loveland (1974) examined 5-alternative choice with pigeons in a changeover-key procedure in which each of five keys were associated with a different color and VI schedule. Consistent matching was observed in 3 of 4 subjects for the relative number of responses to a key and the relative time spent at a key with the relative number of reinforcements at that key. In addition, the relative number of changeovers to a key also matched the relative number of reinforcements at the key.

Elsmore and McBride (1994) examined response and time allocation in rats in an eight-arm radial maze. In Experiment 1, food pellets were delivered at the end of each arm, according to independent fixed interval (FI) schedules. The FI schedules were assigned randomly to each arm with different assignments for each rat. The generalized matching equation was used to assess the response allocation. As such, the log response ratio, the log time ratio, and the log entry ratio were all plotted as a function of the log reinforcement ratio. Results showed that the data for all 6 rats were well described by the generalized matching equation, with some degree of overmatching. In Experiment 2, random-interval (RI) schedules were arranged such that each arm of the maze delivered a pellet according to a different probability that approximated the frequency of pellet delivery from Experiment 1. As in Experiment 1, the data were well described by the generalized matching equation.

Taken together, the results of these studies suggest that the generalized matching equation can be applied to choice contexts employing more than two alternatives. The purpose of the present study was to further extend the generality of the matching law analysis of choice with human subjects and examine the sensitivity of humans' choices to shifting probabilistic contingencies within a three-concurrent choice context.

Adult humans played a series of computer-based games against a computer opponent. The contingencies were based on the familiar childhood game of Rock/Paper/Scissors, in which the probability of winning depends on the opponent: Rock beats Scissors but loses against Paper; Paper beats Rock but loses against Scissors; and Scissors beats Paper but loses against Rock. The programmed probabilities of the computer-opponent responses were systematically altered across 10 blocks of 100 trials each. The results were analyzed in relation to a 3-alternative version of the generalized matching equation. Familiarity with the contingencies of the game enabled subjects to play effectively with minimal instructions. In Experiment 1, no additional instructions were provided. In Experiment 2, accurate probability-related instructions were provided while all other programmed contingencies remained the same. Differences in performance across the two experiments can therefore be attributed to the role of added instructions.

2. Experiment 1

2.1. Method

2.1.1. Subjects

Six undergraduate students (3 male, 3 female) enrolled in an introductory psychology course served as subjects. Subjects received course credit for research participation upon completion of the study according to a preexisting protocol. Subjects were also informed that the highest scorer would receive a $50 gift certificate to the store of their choice. All experimental procedures were approved by the University of Florida Institutional Review Board.

2.1.2. Setting and apparatus

The experimental room was 2.9 m by 1.8 m and contained a desk and chair, a personal computer, a monitor, and a mouse. Experimental manipulations and recording were programmed using VisualBasic.NET®.

2.1.3. Procedure

Upon arrival, a subject was given an informed-consent document to read and sign, and subsequently ushered to the experimental room, where the following instructions were read aloud:

In today's session, you will be playing the childhood game Rock/Paper/Scissors against a computer opponent. The rules are as follows: Rock beats scissors, but loses against paper; paper beats rock, but loses against scissors; and scissors beats paper, but loses against rock. You will make your selection by clicking the mouse pointer on the desired button. The computer will make its selection at the exact same time you do. The winner of each round will receive 5 *points, and the loser will receive* 0 *points. In the event of a tie* (*i.e., both you and the computer choose the same option*)*, both players will receive* 0 *points. How to respond is completely up to you.* PSY2012 (*General Psychology*) *research credit is not dependent on how well you play. However, the subject who scores the most total points in this study will receive a* $50 *gift certificate from the store of their choice, so try to earn as many points as you can. Watches and cellular phones are not allowed in the experimental room. They can be safely stored during the session in an adjacent room. This study will last approximately* 2 h *but will be broken up into several games. The computer will indicate when each game is over. After the completion of each game notify the research assistant, who will then set up the next game. Please only leave the room in the event of an emergency. Do you have any questions*?

After any questions were answered, the research assistant exited the room, and the first block of trials began. The experimental session consisted of ten 100-trial blocks and lasted approximately 2 h.

Upon completion of each block, the computer monitor signaled that the game was complete by displaying a message asking the subject to alert the research assistant in an adjacent room who then started the program for the next block. The program for each trial-block was started by the research assistant to control for time in which additional instructions were delivered in Experiment 2, and also served to delineate the transitions between blocks. Following the 10th and final trial-block of the study, the research assistant debriefed the subject and answered any general questions.

Fig. 1 shows two screenshots of the computer display. The display consisted of clickable rock, paper, and scissors icons for the subject (above) and computer opponent (below) as well as the point totals for the subject and the computer opponent. The subject chose one of the three responses by using the mouse to click the rock, paper, or scissors icon (upper panel of Fig. 1). A click on one of the three designated subject icons resulted in the immediate presentation of the computer opponent's choice. Following each choice, a 5-s intertrial interval was initiated during which the subject's and computer opponent's choice, and updated point totals, were displayed on the screen before transitioning to the next trial (see lower panel of Fig. 1). Mouse clicks on the three computer opponent icons were inoperative throughout the experiment.

The allocation of computer game play (i.e., the computer opponent playing rock, paper, or scissors) during each 100-trial block was determined by programmed probabilities. These programmed probabilities were manipulated across each of the 10 trial-blocks and served as the chief independent variable of this experiment. Table 1 presents the probabilities of each of the computer's three responses during each of the ten 100 trial-blocks. The programmed probabilities for each response were counterbalanced across the

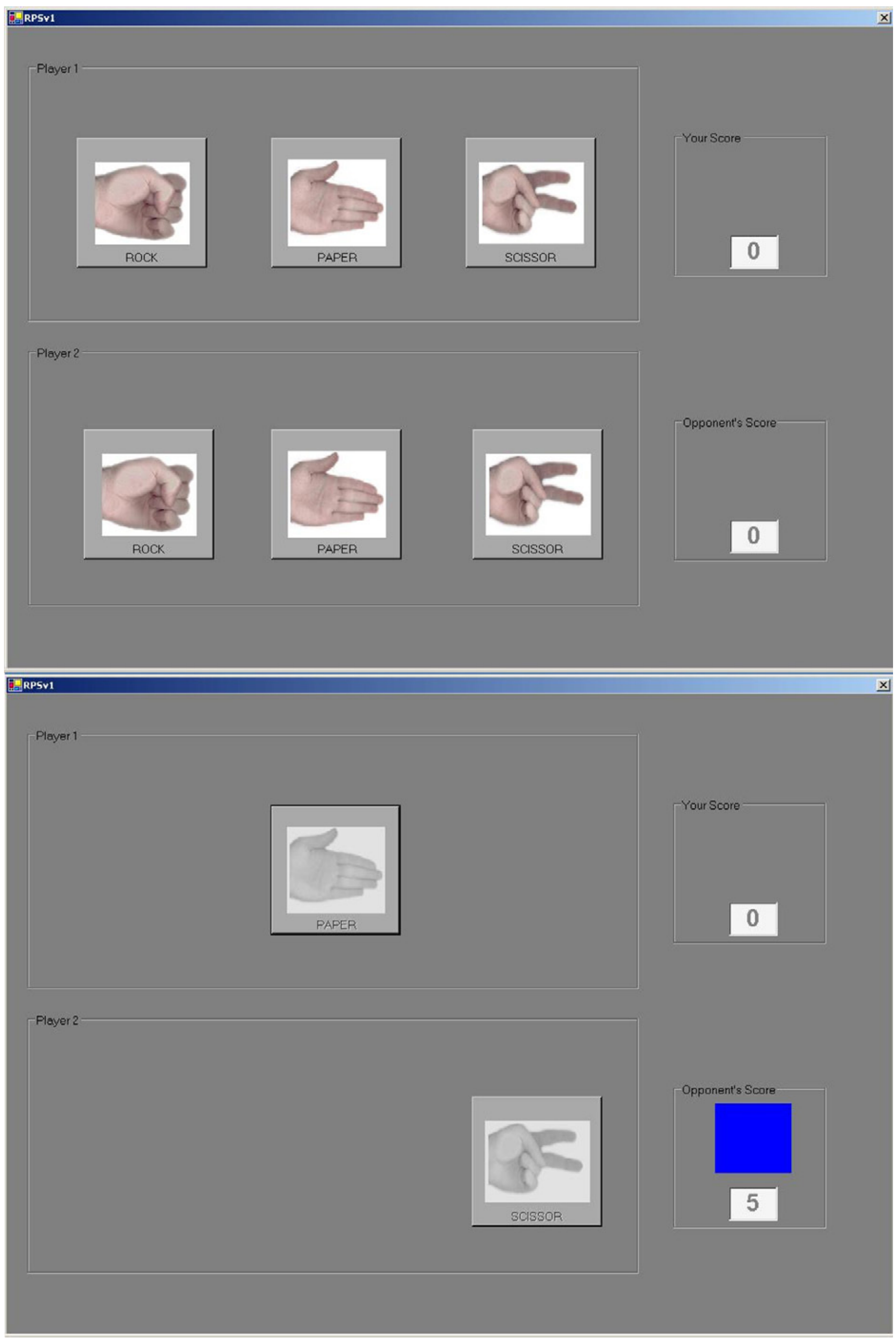

Fig. 1. Screenshots of computer display in Experiment 1 (see text for additional details).

Table 1
Computer opponent's programmed probabilities during each trial-block of the 10-block series.

Trial Block	Rock	Paper	Scissors
1	0.33	0.33	0.33
2	0.20	0.50	0.30
3	0.20	0.10	0.70
4	0.70	0.20	0.10
5	0.05	0.10	0.85
6	0.10	0.85	0.05
7	0.30	0.20	0.50
8	0.85	0.05	0.10
9	0.10	0.70	0.20
10	0.50	0.30	0.20

blocks according to the following rules: Excluding the first block (where each response was programmed to play approximately 0.33 of the time), no response had the same numerical probability value. Each probability fell within a range of 0.05–0.85, and every probability was a multiple of 0.05. To reduce the potential for bias, each response was the most probable outcome in exactly 3 blocks, and none were most probable across two consecutive blocks.

3. Results and discussion

Fig. 2 displays the log response ratios plotted as a function of the log reinforcement ratios for each subject. Each data point represents the log response ratio of a single response as a function of the log reinforcement ratio for playing that response within a single trial-block. The closed circles, open squares, and X's represent rock, paper, and scissors, respectively. Thus, each response (i.e., Rock, Paper, and Scissors) was examined individually as a ratio of the number of responses of one response over the number of responses for the other two responses compared to the number of winning trials playing that response over the number of winning trials playing the other two responses. For example, in the analysis of Rock as a target response, the response-allocation ratio of Rock over Paper and Scissors was compared to the ratio of the number of winning trials playing Rock over the number of winning trials playing Paper and Scissors. Fig. 2 therefore depicts the aggregate total of subject and computer opponent game play across the entire session—a composite representation displaying the overall matching relation. A composite generalized matching equation of total subject and computer opponent game play can be expressed as

$$\log\left(\frac{B_i}{B_o}\right) = a\log\left(\frac{R_i}{R_o}\right) + \log k \quad (3)$$

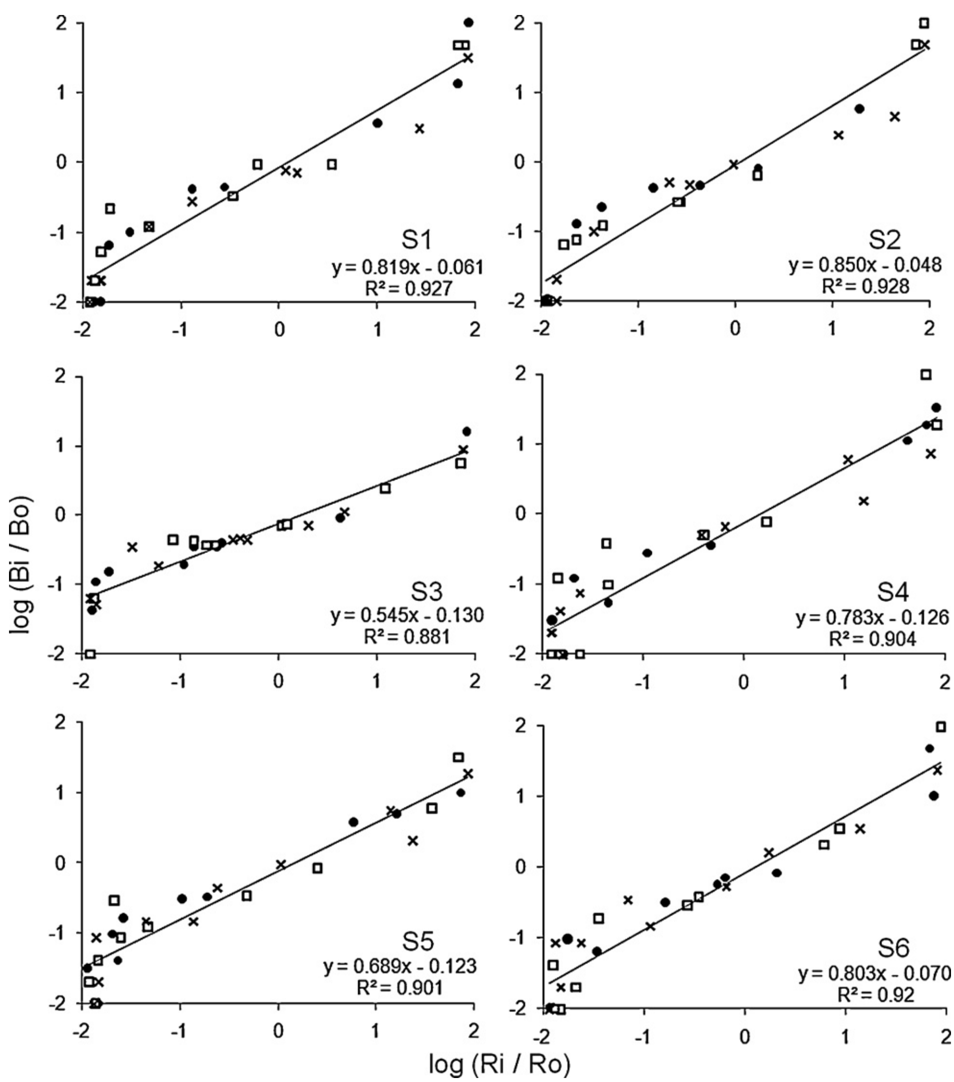

Fig. 2. Log response ratios as a function of log reinforcement ratios for all subjects in Experiment 1. Each data point represents the log response ratio of a single response as a function of the log reinforcement ratio for playing that response within a single trial-block. Filled circles indicate rock as the target computer response, open squares indicate paper as the target computer response, and X's indicate scissors as the target computer response (see Appendix A for individual subject response allocation data).

Table 2
Least squares fits of Eq. (2) for individual subjects in Experiment 1. The slope, intercept, and r^2 are shown when Rock, Paper, and Scissors were the target. Also shown are the composite fits and total scores (cumulative number of points) for each subject.

	Configuration	r^2	a	k
S1	Rock	0.932	0.86	−0.05
	Paper	0.923	0.81	0.06
	Scissors	0.954	0.78	−0.20
	Composite	0.927	0.82	0.81
	Total score	2940		
S2	Rock	0.912	0.88	0.01
	Paper	0.956	0.90	0.04
	Scissors	0.931	0.79	−0.16
	Composite	0.928	0.85	0.81
	Total score	2930		
S3	Rock	0.927	0.55	−0.10
	Paper	0.835	0.58	−0.15
	Scissors	0.914	0.50	−0.14
	Composite	0.881	0.55	0.74
	Total score	2565		
S4	Rock	0.949	0.80	−0.12
	Paper	0.871	0.86	0.01
	Scissors	0.927	0.70	−0.26
	Composite	0.904	0.78	0.75
	Total score	2875		
S5	Rock	0.916	0.68	−0.10
	Paper	0.885	0.70	−0.10
	Scissors	0.909	0.69	−0.17
	Composite	0.901	0.70	0.75
	Total score	2935		
S6	Rock	0.928	0.80	−0.11
	Paper	0.933	0.89	−0.04
	Scissors	0.915	0.73	−0.06
	Composite	0.920	0.80	0.85
	Total score	2915		

where B_i represents the number of responses to a given Rock, Paper, or Scissors target alternative, as denoted by the subscript i, R_i represents the number of winning trials of the target response, and B_o and R_o are the sums of behavior and winning trials from the other two response alternatives. The slope of the equation is denoted by a, which measures sensitivity of behavior to programmed reinforcement, and the y-intercept of the equation is denoted by k, which measures bias for one alternative that is unaccounted for by programmed reinforcement contingencies. The solid line in each panel represents the least squares fit of the composite equation to the data (computed with the Solver add-in in Microsoft Excel®). Data from each of the individual ratio configurations with Rock, Paper, and Scissors for each subject are displayed in Table 2. (Individual subject data of the number of Rock, Paper, and Scissors responses of both subject and computer are shown in Appendix A in Supplementary Data.) No consistent differences in responding, either between or within subject, were observed depending on the ratio configurations, indicating that the overall matching relation derived from the composite equation (Eq. (3)) provides a reasonably representative characterization of the individual ratio configurations.

Overall, the data were well characterized by the generalized matching equation: Across subjects, Eq. (2) accounted for 88–92% of the variance in response ratios, although it should be noted that the R^2 values are inflated because the data points are not all calculated from independent values, (i.e., Rock/Paper + Scissors; Paper/Rock + Scissors; Scissors/Rock + Paper). Characteristic sensitivity values (a parameter) indicating undermatching (see Baum, 1979; Wearden and Burgess, 1982, for reviews) were observed in all subjects in the present experiment.

The observed undermatching extends the generality to atypical schedules. Whereas the majority of concurrent-schedule research has used VI schedules, the present experiment used probabilistic schedules, which are more akin to variable ratio (VR) schedules. That is, a response on a given alternative was reinforced probabilistically according to the relation between a subject's response and the computer's response (determined by the programmed probabilities listed in Table 1). Thus, in effect, reinforcement was delivered after a variable number of responses to a given alternative, hence, a VR schedule. The typical result on concurrent ratio schedules is exclusive preference for the schedule with the lower ratio requirement (e.g., Herrnstein, 1970; Herrnstein and Loveland, 1975; MacDonall, 1988), a pattern that maximizes the overall reinforcement rate. None of the subjects in the present experiment, however, displayed such exclusive preference.

4. Experiment 2

Because responding was distributed across alternatives, none of the subjects in Experiment 1 maximized overall reinforcement rates. Perhaps with additional probability-related information, the subjects would come to respond more exclusively on the most favorable option. To test this, subjects in Experiment 2 were provided with supplementary instructions that accurately portrayed the computer opponent's programmed response probabilities. Subjects were exposed to the same series of probabilities as in Experiment 1, but with accurate probability-related instructions.

5. Method

5.1. Subjects, setting, and apparatus

Six undergraduate students (3 male, 3 female) served as subjects. All other conditions were as in Experiment 1.

5.2. Procedure

Subjects reported to the experimental room, read and signed the informed consent, and were seated in front of the computer in the same manner as described in Experiment 1. Prior to the first trial-block, instructions identical to those in Experiment 1 were presented followed by the addition of the following statement:

The computer is programmed to play Rock __% of the time, Paper __% of the time, and Scissors __% of the time.

The research assistant also read aloud the aforementioned statement before each trial-block according to the predetermined probabilities. These probabilities, which accurately conveyed the computer opponent's programmed probabilities of each response were also visually represented above the computer opponent's icons throughout each block. The computer opponent's programmed probabilities in Experiment 2 were identical to those in Experiment 1 (see Table 1). As in Experiment 1, after the final trial-block, subjects were debriefed and any general questions were answered.

6. Results and discussion

Fig. 3 displays the log response ratios plotted as a function of the log reinforcement ratios depicting the aggregate total of game play across the 10 trial-blocks. (Individual subject data of the number of Rock, Paper, and Scissors responses of both subject and computer are displayed in Appendix B.) Therefore Fig. 3, like Fig. 2, depicts the overall (composite) matching relation for each subject. The closed circles, open squares, and X's represent rock, paper, and scissors, respectively. The solid line in each frame represents the least squares fit of Eq. (3) to the data. The slope, intercept, and r^2 from individual ratio configuration analyses of Rock, Paper, and

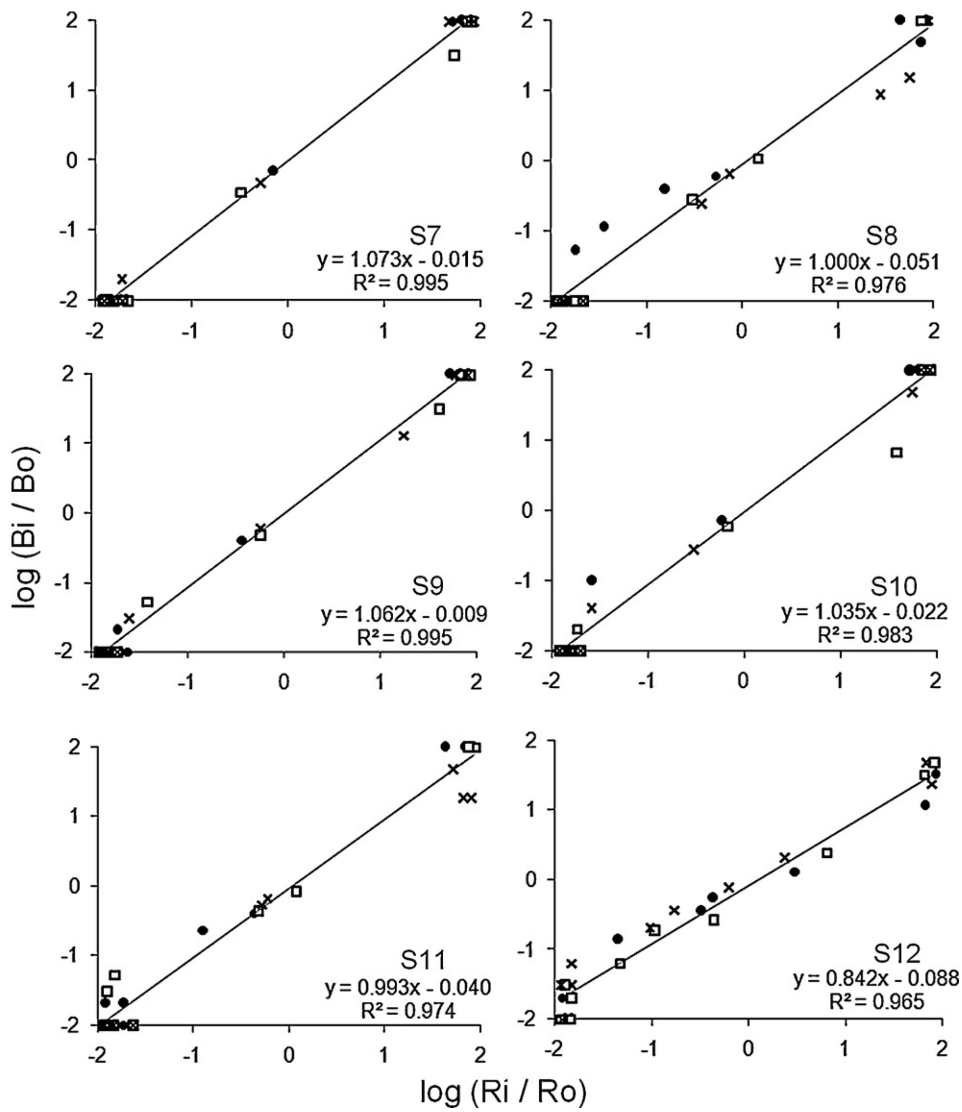

Fig. 3. Log response ratios as a function of the log reinforcement ratios for all subjects in Experiment 2. Each data point represents the log response ratio of a single response as a function of the log reinforcement ratio for playing that response within a single trial-block. Filled circles indicate rock as the target computer response, open squares indicate paper as the target computer response, and X's indicate scissors as the target computer response (see Appendix B for individual subject response allocation data).

Scissors as a target are displayed in Table 3. As in Experiment 1, no consistent differences in configuration responding were observed, so the focus of the remaining analyses will be on the composite results.

The overall pattern of results described by Eq. (2) accounted for a high percentage of variance, ranging from 96% to 99%, across subjects, but again, these values are inflated due to a lack of independence of the values used to calculate, as well as a violation of homoscedasticity discussed below. Unlike Experiment 1, slight overmatching was observed; five of 6 subjects responded in near-exclusive fashion, as indicated by the response ratios approaching 2 and −2. (In the event of zero responses to an alternative, 1 replaced the zero, as the log of zero is not defined.) The exception was Subject 12, whose sensitivity values were more in line with those seen in Experiment 1.

The near-exclusive response allocation resulted in point totals for subjects in Experiment 2 (accurate probability-related instructions) higher than for those in Experiment 1 (no probability-related instructions). The mean score, averaged across subjects, was 2860 points in Experiment 1 and 3172.5 points in Experiment 2 (see Tables 2 and 3 for individual subject scores). These differences were significant in that the distributions of scores across the two experiments were non-overlapping (i.e., the lowest score in Experiment 2 was higher than the highest score in Experiment 1), and also statistically significant (t [5] = 5.138, $p < .004$). The accurate instructions therefore appeared to enhance sensitivity to the contingencies, producing near-maximum reinforcement rates for most subjects.

It is possible that the contingency descriptions in Experiment 2 merely facilitated adjustment to the new contingencies at the outset of each block, and with extended exposure to the contingences, subjects in Experiment 1 would have ultimately performed as well as those in Experiment 2. If so, then one would expect performance to improve (i.e., become more exclusive) across trials within a block for subjects in Experiment 1. To determine whether this happened, we divided each 100-trial-block into 5 bins of 20 trials each and fit Eq. (2) separately to the data from each of the successive bins in each block. As Fig. 4 shows, slight increasing trends in the measure of sensitivity (a) were observed in all 6 subjects in Experiment 1. This analysis suggests that with additional exposure to the contingencies, choice proportions may come increasingly to favor one alternative like those in Experiment 2. For 5 of the 6 subjects, sensitivity values in the final 20-trial block were approaching those seen in Experiment 2, providing further evidence that the

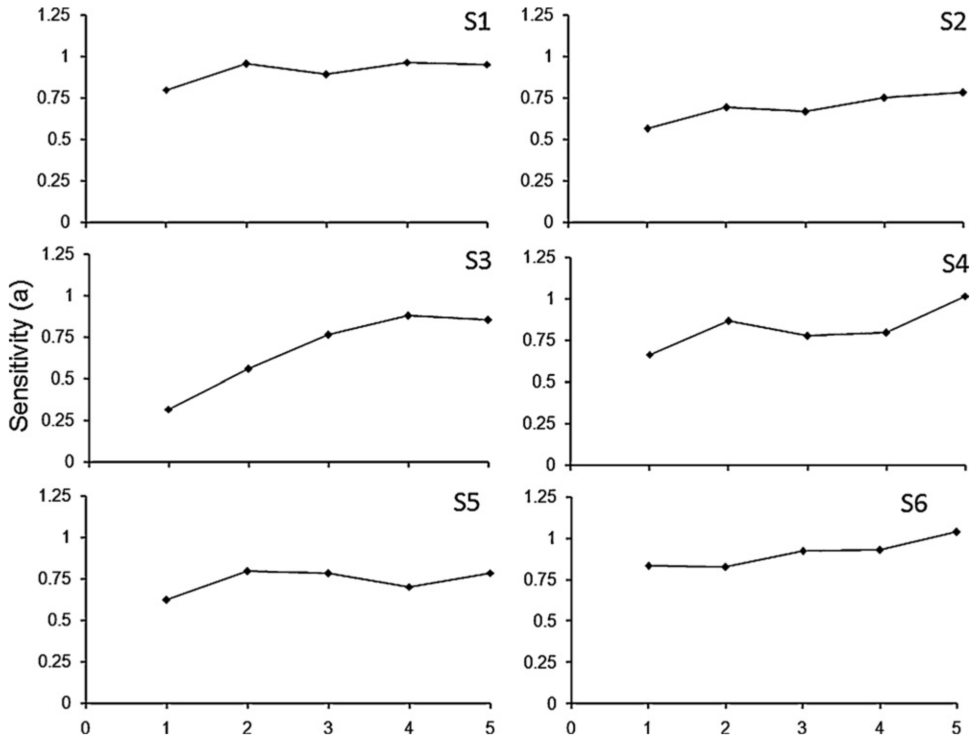

Fig. 4. Sensitivity to reinforcement (i.e., the a parameter in Eq. (3)) fit separately across each 100-trial-block separated into 5 bins of 20 trials.

Table 3
Least squares fits of Eq. (2) for individual subjects in Experiment 2. The slope, intercept, and r^2 are shown when Rock, Paper, and Scissors were the target. Also shown are the composite fits and total scores (cumulative number of points) for each subject.

	Configuration	r^2	a	k
S7	Rock	0.997	1.09	0.00
	Paper	0.995	1.05	−0.07
	Scissors	0.997	1.08	0.02
	Composite	0.995	1.07	0.63
	Total score	3285		
S8	Rock	0.975	0.98	0.13
	Paper	0.996	1.07	−0.05
	Scissors	0.986	0.95	−0.21
	Composite	0.976	1.00	0.84
	Total score	3170		
S9	Rock	0.995	1.08	0.01
	Paper	0.995	1.05	−0.03
	Scissors	0.995	1.05	−0.01
	Composite	0.995	1.06	0.89
	Total score	3155		
S10	Rock	0.985	1.06	0.08
	Paper	0.978	0.99	−0.14
	Scissors	0.994	1.05	−0.01
	Composite	0.983	1.05	1.24
	Total score	3165		
S11	Rock	0.993	1.05	0.10
	Paper	0.968	1.01	0.01
	Scissors	0.982	0.93	−0.22
	Composite	0.974	0.99	0.62
	Total score	3185		
S12	Rock	0.966	0.82	−0.19
	Paper	0.981	0.88	−0.12
	Scissors	0.972	0.82	0.04
	Composite	0.965	0.84	0.79
	Total score	3075		

instructions served mainly to facilitate the rate of acquisition to the contingencies.

7. General discussion

The present experiments examined humans' allocation of responding in a gaming context, and extended the application of the generalized matching law to a 3-alternative choice situation. Although the generalized matching law described the relation between reinforcement and response ratios from both experiments, the data from Experiments 1 and 2 were notably different. In Experiment 1, with minimal instructions, responses probabilistically matched the counter responses of the computer opponent's programmed probabilities during the session. In Experiment 2, with accurate probability-related instructions, slight overmatching in the form of near-exclusive responding on the appropriate counter response, was observed in 5 of 6 subjects. The delivery of accurate-probability instructions was related to a different game-play strategy, which produced near maximum obtained reinforcement rates. These results, therefore, suggest that the delivery of accurate probability-related instructions enhanced game-play performance.

Eq. (3) accounted for a high percentage of the variance in both experiments. It should be noted, however, that the percentage of variance accounted for alone can be a misleading index of the appropriateness of a given quantitative model to a data set. As McDowell (2005) pointed out, in addition to a high variance accounted for, the assumption of homoscedasticity (i.e., variability in values for one variable is approximately the same at all values of the other variable) must not be violated. Inspection of the data points around the fitted line in Figs. 2 and 3 show some systematic departures from the fitted line (i.e., the line systematically under- and then over-estimated the obtained data points as the reinforcement ratio increased). Therefore, the data for most subjects may be better described with another model (e.g., a step function or sigmoid). For example, Natapoff's (1970) model has recently been used successfully in accounting for data collected under situations of greater than two concurrent choice (e.g., Aparicio and Cabrera, 2001; Schneider and Davison, 2005). For the purposes of the present investigation, however, we can conclude that the generalized matching law provides a reasonably accurate description of response allocation in a multi-response environment. Whether, and the extent to which, these other models capture response allocation in such environments is a topic that might be profitably explored in future research.

Previous research assessing the matching relation within a gaming context has shown that matching response allocation to reinforcement on separate alternatives maximizes reinforcement (e.g., Reed et al., 2006; Vollmer and Bourret, 2000). Results of the present experiment, however, indicate that probabilistic matching of responses to reinforcement is not optimal within this choice situation. Instead, responding exclusively to the highest probabilistic alternative yields consistently higher rates of reinforcement. This disparity with the previous literature is likely due to both the difference in game and the present use of probabilistic schedules, with ratio-like properties. Such schedules tend to produce exclusive preference for the richer alternative, as noted by several authors (e.g., Herrnstein, 1970; Herrnstein and Loveland, 1975; MacDonall, 1988) and demonstrated empirically in the literature on probability matching (e.g., Bailey and Mazur, 1990; Brunswik, 1939; Estes, 1964; Graf et al., 1964; Shimp, 1966).

The subjects in Experiment 2 earned more points than subjects in Experiment 1, which suggests that the probability-related descriptions facilitated contact with the contingencies. Five of 6 subjects adopted an exclusive-game play strategy that approximated maximization of earnings. It should be noted that these contingency descriptions were not rules about *how* to play; they were merely descriptions of the computer's distribution of choices. Nevertheless, the descriptions likely functioned as a kind of instruction that enhanced control by the programmed contingencies. As such, the results join with others in showing that instructions can facilitate contact with contingencies (e.g., Hayes et al., 1986; LeFrancois et al., 1988). In addition to the beneficial effects of instructions, prior research has also shown that instructions may impair sensitivity to changes in contingencies (Galizio, 1979; Hackenberg and Joker, 1994). In the Hackenberg and Joker study, instructional control was examined as a function of the degree of instructional accuracy—the extent to which the instruction corresponded with the contingencies. Similar manipulations could be incorporated in the present gaming context, both by changing the probabilistic contingencies across blocks of trials while holding constant the instructions, or by changing the instructions while holding constant the contingencies.

An interesting aspect of the present study is the reinforcing nature of gaming with a computer opponent. Previous studies suggest that game play may function as a reinforcer for human subjects (e.g., Case et al., 1990; Chumbley and Griffiths, 2006; Millar and Navarick, 1984). For example, Case et al. (1990) found the discovery and destruction of enemy Klingons within a popular simulated Star Trek game to serve as reinforcers. They also suggested that the reinforcement obtained through game play and point delivery may be different: "Although there is little doubt that monetary backing or instructions can be effective in making points themselves reinforcing (Case and Fantino, 1989; Navarick, 1985), there may be different properties between reinforcing stimuli established in this manner and those that are well-integrated into a realistic simulation (p. 13)." The competitive nature of simulated Rock/Paper/Scissors game play against a computer opponent likely provides similar reinforcing properties. The reinforcing properties of game play and established conditioned reinforcers such as points, however, may be very different. This, too, is a topic for future research.

To conclude, the present study successfully extended the use of the generalized matching law to human game play in a greater than two-concurrent choice situation. The use of a familiar game likely enhanced control by the contingencies, permitting the collection of extensive and quantitatively interpretable data in a relatively brief period of time. The use of multi-alternative choice with and without supplementary instructions is important in the extension of laboratory findings to everyday human choice contexts, which frequently involve incomplete information among a myriad of alternatives. Although still preliminary, the present findings illustrate a promising set of procedures and analytic techniques for examining human choice under laboratory conditions that capture some important features of everyday human choice.

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Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.beproc.2009.06.004.

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