CHOICE IN THE REPEATED-GAMBLES EXPERIMENT

ALAN SILBERBERG, PAUL MURRAY, JOYCE CHRISTENSEN, AND TOSHIO ASANO

THE AMERICAN UNIVERSITY AND KYOTO UNIVERSITY

Humans chose 10 times between two roulette wheels projected on a monitor. During the first trial, the left wheel provided a hypothetical \$100 with $p = .94$, and the right wheel provided \$250 with $p = .39$. A titration procedure adjusted the probability of a \$250 win across trials to permit estimation of an indifference point between alternatives. In Experiment 1, intertrial-interval duration (25 vs. 90 s) and whether sessions began with an intertrial interval or a trial were varied in a 2×2 design in this risky-choice procedure. Risk aversion (preference for the \$100 wheel) increased with intertrial interval but was unaffected by whether sessions began with a trial or an intertrial interval. In Experiment 2, all sessions began with a trial, and subjects were informed that the experiment ended after 10 trials. Intertrial-interval duration had no effect on choice. In Experiment 3, intertrial-interval duration and whether subjects were given \$10 or \$10,000 before beginning were varied among four groups in a 2×2 design. In all other ways, the procedure was unchanged from Experiment 2. Intertrial interval had no effect on choice, but the \$10,000 groups showed less risk aversion than the \$10 groups. These results can be explained more readily in terms of Kahneman and Tversky's (1984) notion of "framing of the prospect" than in terms of Rachlin, Logue, Gibbon, and Frankel's (1986) behavioral account of risky choice.

Key words: risky choice, risk aversion, repeated gambles, choice, matching, humans

Rachlin, Logue, Gibbon, and Frankel (1986; see also Rachlin, Castrogiovanni, & Cross, 1987) have explained important features of human risky choice (Kahneman & Tversky, 1984) in terms of the matching law (de Villiers, 1977). They view their success in interpreting cognitive data in terms of a behavioral rule as holding the promise of unifying cognitive and behavioral approaches to the study of choice. Such a unification would mean that the differences between cognitive and behavioral approaches are more the result of differences in approaches to research and description than of differences in the processes modeled by each approach. In this report, we review these arguments and test this thesis. First, we illustrate the cognitive approach by summarizing a risky-choice experiment by Kahneman and Tversky and their interpretation of the results. Then we review Rachlin et al.'s (1986) reinterpretation of these results in terms

of matching theory and their experimental test of their behavioral account. Finally, we offer a separate test of Rachlin et al.'s (1986) account.

The Kahneman and Tversky Account

In Problem 4 from Kahneman and Tversky (1984), subjects made a pair of risky choices. One choice was between earning \$240 with certainty versus earning \$1,000 with a 25% likelihood, and the other was between losing \$750 with certainty versus a 75% chance of losing \$1,000. They found that subjects avoided the risky choice when money was to be gained, but sought risk when money was to be lost.

To explain this finding, Kahneman and Tversky posited that their subjects made two transformations, one of the amounts to be gained or lost, and the other of the probability of a gain or loss. The first transformation, presented as a hypothetical value function in the top half of Figure 1, shows that marginal changes in value decrease with the size of the amount to be gained or lost. Further, Kahneman and Tversky assumed that this transformed valuation of money is weighted by a subjective probability function that, relative to actual probabilities, overstates low likelihood events, understates moderate and high likelihood events, and accurately reflects certainties (see bottom half of Figure 1). Kahneman and

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Fig. 1. A hypothetical value function (top) and a hypothetical weighting function (bottom). (From "Choices, Values, and Frames" by D. Kahneman and A. Tversky, 1984, *American Psychologist*, 39, p. 342 and p. 345. Copyright 1984 by the American Psychological Association. Reprinted by permission.)

Tversky used these two transformations to predict the results of Problem 4.

The Behavioral Reinterpretation of Rachlin et al. (1986)

Rachlin et al. note that the value function in the top half of Figure 1 can be modeled directly in terms of the matching law. To illustrate, the matching law for reinforcer amounts states:

$$B_1/B_2 = (A_1/A_2)^s \quad (1)$$

where B , A , and s stand for behavior, reinforcer amounts, and sensitivity to the reinforcer ratio, respectively, and the subscripts distinguish choice alternatives. When applied to money

amounts with $s < 1$, this equation duplicates the cognitive theory prediction that large gains and losses are underweighted relative to smaller gains and losses.

Rachlin et al. (1986) modeled the decision-weighting function in the bottom half of Figure 1 by demonstrating that the matching law produces the appropriate functional form when choice is presented in a repeated-gambles experiment. In this type of experiment, a subject chooses one of two spinning arrows, each of which rotates over a disk of 18 equal-sized, wedge-shaped sectors. The left spinner, called the sure thing, is composed of 17 white sectors and one black sector. The right spinner, called the risky gamble, is initially composed of 7 white and 11 black sectors. If the sure thing is selected, the spinner is spun and that choice pays \$100 if the outcome is white, and nothing if the arrow points to the one black sector. If the risky gamble is selected, a successful gamble (arrow pointing to a white sector following a spin) pays \$250.

Choice allocation is regulated by a titration procedure: If, on the prior trial, a subject chooses the sure thing, a black sector is replaced with white on the risky gamble side, making that side less risky; if the risky spinner has been selected on the prior trial, a white sector on that side is replaced with black, making that side more risky. As a consequence, an indifference point between the two spinners can be defined, measured in terms of the number of black sectors on the risky gamble side at the end of a session. Except for the first trial, each of the 10 trials composing each subject's single session was preceded by an inter-trial interval (ITI) of approximately 30 or 90 s, depending on the group.

Rachlin et al. (1986) modeled the decision-weighting function of Figure 1 by incorporating the expected time to the subject's first win in this experiment within a general matching equation that included reinforcer ratios for rates and delays as well as for amounts. First, the expected delay (D) to first win is

$$D = (t + c)/p - t \quad (2)$$

where c , t , and p stand for the time that the spinner operates, the ITI, and the probability of a win, respectively. Next, they define the broadened matching equation as:

$$B_1/B_2 = (A_1/A_2)^{sa}(R_1/R_2)^{sr}(D_2/D_1)^{sd}, \quad (3)$$

where R stands for rate of reinforcement, and

sa, *sr*, and *sd* define sensitivity to the ratios of reinforcer amounts, rates, and delays, respectively. They simplify this equation by noting a confound in the repeated-gambles experiment: A change in the probability of reinforcement changes both the reinforcement rate and the delay to reinforcement. For example, if the probability of reinforcement is halved, so is the rate of reinforcement, but the average delay between a response and a reinforcement is doubled. Because probability can be expressed as either a rate or as a delay in the matching law, and because there is an inverse relation between delay and rate in the present experiment, Equation 3 becomes:

$$B_1/B_2 = (A_1/A_2)^{sa}(D_2/D_1)^{sr+sd}. \quad (4)$$

To compare this equation with the figure in the bottom half of Figure 1, Equation 2 is substituted for *D* in Equation 4. Then with $c_1 = c_2 = 0.2$, $t_1 = t_2 = 1$, $p_1 = p$, $p_2 = 1$, and $A_1 = A_2$, B_1/B_2 is plotted as a function of p for different values of $sr + sd$. When $sr + sd = 0.5$, a decision-weighting function is generated that is comparable to that in the bottom panel of Figure 1.

The capacity of this behavioral account to reproduce the hypothetical functions represented in Figure 1 at least ensures its predictive equivalence to Kahneman and Tversky's (1984) account. But Rachlin et al. (1986) took their account further by using the repeated-gambles experiment as a critical test of behavioral and cognitive accounts.

Recall that in the repeated-gambles experiment, groups differed only in terms of their ITIs. Using Equations 2 and 4, and assuming $A_1 = 100$, $A_2 = 250$, $c_1 = c_2 = 5$, $t_1 = t_2 = t$, and $sa = sr + sd = 1$, it can be shown at choice equilibrium ($B_1/B_2 = 1$) that p_2 approaches 1 as t (the ITI) increases. Thus, the model predicts that subjects should be more averse to risk as the ITI increases. This prediction was corroborated in the study by Rachlin et al. (1986): Across the 10 trials composing each session, subjects in the short-ITI condition were risk seeking, and those in the long-ITI condition were risk averse.

Significance

Rachlin et al. (1986) have created a procedure and a model that accommodate cognitive tests and interpretations of risky choice in a manner compatible with behavior-analytic approaches. This is surprising in that their

experiment differed from most behavior-analytic studies in that it lasted only one session and produced only a single datum that was averaged over individuals. Despite these important procedural differences, their results suggest that cognitive and behavioral methods share much in common, and, at the limit, that a unification of these fields may be realizable. In our view, this possibility is significant enough to warrant replication of their study.

EXPERIMENT 1: A REPLICATION OF RACHLIN ET AL. (1986)

In this experiment, we repeated Rachlin et al.'s experimental procedure with two changes. First, we automated their procedure, replacing the experimenter with a computer that presented the alternatives and recorded each subject's choices. Second, for some subjects, each 10-trial session began with a trial; for others each session began with an ITI. We expected to reproduce Rachlin et al.'s results, despite these procedural changes.

METHOD

Subjects

One hundred one subjects served in this experiment. Thirty subjects were employees of the U.S. Environmental Protection Agency, and 70 were undergraduate students in introductory-level psychology courses at The American University. Of the subjects across the three experiments of this report, 74% were female. In a pilot study prior to this experiment, where gender of subject was recorded, there were no apparent differences in behavior as a function of the subject's gender.

Apparatus

The experiment was conducted in a small sound-attenuated room containing a chair and a table. A microcomputer with keyboard and a monochrome monitor were on the table.

Procedure

Subjects were assigned to one of four conditions in a 2×2 design; for half the subjects, sessions began with a trial and for the other half, sessions began with an ITI. For half of each of these groups, the ITI was 25 s, and for the other half it was 90 s.

Following assignment to the appropriate

condition, the experimenter read the following instructions to the subject:

The purpose of this experiment is to see how you judge various imaginary gambles. Two roulette wheels will appear on the monitor. A gamble takes place when you press the "A" or "B" key on the keyboard. Your job is to choose which of the two roulette wheels you prefer. If the rotating "dollar sign" lands on white, you win. On your left the hypothetical amount would be \$100. On your right the hypothetical amount would be \$250. If the rotating dollar sign lands on black you win nothing. After each gamble the computer may change the odds by turning over one or more chips from black to white or white to black. Please do not try to calculate odds or plan ahead. Just judge the gamble that most appeals to you in each case. You must make your choice within 10 seconds after the choice is presented.

After reading these instructions and showing the subject the "A" and "B" keys on the keyboard, the session began, with either a trial or with an ITI of 25 or 90 s.

During a trial, two roulette wheels (each with an outside diameter of 7.5 cm and an inside diameter of 5 cm) were projected side by side on the monitor. Written inside the inner circle of the left wheel was "A" and just below it, "\$100"; inside the right wheel, "B" and "\$250" were written. Below both wheels the following text appeared on the monitor screen: "Which side do you bet (A or B)?"

Depending on which letter was pushed on the keyboard ("A" for left wheel, "B" for right wheel), a dollar sign appeared on the appropriate wheel and spun for 5 s. Although the spinning time was fixed, the dollar sign landed with the same probability on any of the 18 equally sized sectors of the wheel. If the sector landed on was white, the monitor flashed the response "You won!"; if the sector landed on was black, the monitor flashed "You lost." After flashing this message for 1 s, the wheels disappeared and the word "WAIT" appeared on the screen, indicating the beginning of the ITI. Below this message was another indicating how much money had been earned through the previous trial (e.g., "Total winnings = \$100").

For the left wheel, where winning resulted in earning \$100, 17 sectors were white and only one was black. For the right wheel, where winning resulted in a gain of \$250, seven consecutive sectors were white and 11 were black during the first trial. If the left wheel were

selected on the previous trial, a right-wheel black sector turned white for the next trial. Alternatively, if the right wheel had been selected on the previous trial, a right-wheel white sector turned black for the next trial.

If the subject did not choose "A" or "B" within 5 s following the presentation of the wheels, the message "RESPOND NOW" flashed on the screen. If the subject did not respond during the next 5 s, the session was terminated automatically. In all other cases, the session ended after 10 trials.

RESULTS

Figure 2 presents the within-session changes in the number of white sectors in the right roulette wheel. The two left panels present the 25- and 90-s group data as a function of whether the session began with a trial (top panel) or an ITI. The two right panels organize the same data in another way, comparing trial against ITI groups when both had a 25-s ITI (top panel) and a 90-s ITI (bottom panel). (One subject was dropped from the experiment for having a response latency greater than 10 s.)

The number of white sectors in the right roulette wheel after Trial 10 was compared across the four groups (Trial vs. ITI $\times$ 25 s vs. 90 s) by a Kruskal-Wallis test. Significant between-group differences emerged, $H(3) = 15.8$, $p < .05$. Pairwise post hoc contrasts (Conover, 1980) revealed the following: (a) the 25-s ITI group was significantly less averse to risk than the 90-s ITI group; (b) the 25-s trial group was significantly less averse to risk than the 90-s trial group; and (c) there were no significant differences between the two 25-s groups or the two 90-s groups as a function of whether they began with a trial or an ITI.

DISCUSSION

Despite some differences in procedure, the results of the present experiment replicate those of Rachlin *et al.* (1986). This empirical correspondence enables us to use this procedure to test alternative interpretations of their results. One hypothesis is that their results were caused by subjects' implicit expectations about how long the experiment should last. If, on average, the subjects in each group guessed that the experiment would last for the same time, then subjects in the 25-s ITI condition would expect roughly three times the income as subjects in the 90-s ITI condition.

Kahneman and Tversky (1984) already have shown that people often evaluate gains and losses in relative rather than absolute terms. Perhaps such a *framing effect* is present in the Rachlin et al. (1986) procedure: If the short-ITI subjects expect more trials in their sessions than do the long-ITI subjects, and if subjects frame their prospective gains in relative terms, then the short-ITI subjects should perceive themselves as having less to gain in choosing either alternative than do the long-ITI subjects. This between-group difference in gain can be represented on the "gains" axis of Figure 1 by placing the \$100 and \$250 points closer to the origin for the short-ITI subjects than for the long-ITI subjects. Because the value function is negatively accelerated for gains, the \$250/\$100 value ratio is greater for the short-ITI subjects than for the long-ITI subjects, leading to the prediction that the short-ITI group will show less risk aversion.

In the next experiment we tested our thesis that an implicit frame was constructed by the greater trial density of the short-ITI conditions, leading to lessened risk aversion for those groups.

EXPERIMENT 2: THE EFFECT OF KNOWLEDGE OF THE NUMBER OF TRIALS ON BETWEEN-GROUP DIFFERENCES IN REPEATED GAMBLER

In this experiment, we informed subjects in both the 25-s and 90-s ITI conditions that the session ended after 10 trials. In addition, the computer monitor presented the number of trials remaining throughout the session. Because both groups should share the same view of the amounts to be gained regardless of their ITIs, we expected no between-group difference in risky choice.

METHOD

Subjects and Apparatus

Twenty undergraduate students from introductory-level courses in psychology at The American University served as subjects. The apparatus was the same as that used in Experiment 1.

Procedure

The subjects were assigned randomly to two 10-subject groups, one with a 25-s ITI and

the other with a 90-s ITI. For both groups, sessions began with a trial. The directions read to each subject were the same as in Experiment 1, except that the following sentence was added to the end: "This experiment will end after 10 trials. The number of trials remaining in the experiment will also be provided to you on the computer monitor." Consistent with this last statement, the computer program was altered so that the number of trials remaining was continually updated during the session by printing the phrase "*X* trials remain" during each ITI. All other features of the experiment were the same as in Experiment 1.

RESULTS AND DISCUSSION

Figure 3 shows there were no differences in risky choice between the short- and long-ITI groups. This result is consistent with our explanation for the results of Experiment 1 and those of Rachlin et al. (1986). That is, in this experiment, unlike the others, there was no possibility of a differential framing effect because all subjects knew that the session ended after 10 trials.

This interpretation can be tested in a complementary experiment in which the frame is explicitly manipulated. If one group of subjects is told that they start their sessions with \$10,000 and another group is told that they start their session with \$10, we would expect the former group to be less averse to risk than the latter group. Moreover, if subjects were still informed of the number of trials in a session, we would expect this result to hold whether ITIs are of 25-s or 90-s duration. These predictions are tested in the next experiment.

EXPERIMENT 3: EXPLICIT MANIPULATION OF FRAME IN REPEATED GAMBLER

METHOD

Subjects and Apparatus

Forty American University undergraduates, all students in introductory-level psychology courses, served as subjects. The apparatus was the same as in the previous experiments.

Procedure

The subjects were randomly assigned to two 20-member groups. All subjects were read instructions that were amended from those of

Fig. 2. Mean probability of a win (number of white sectors) for the risky gamble (right roulette wheel) as a function of trials. Two panels on the left show the effects of ITI on choice depending on whether the session began with a trial (top panel) or an ITI (bottom panel). Two panels on the right present the same data plotted to compare the effects of beginning with a trial or an ITI for the 25-s ITI group (top panel) and the 90-s ITI group (bottom panel).

Experiment 2 by adding the following: “Finally, you will be given a sum of money before you start gambling. The amount will also be presented on the computer monitor.” For each subject, the computer monitor read before the roulette wheels were presented: “Congratulations, you have been given (\$10 or \$10,000) before you begin gambling!” Each group was then divided into two 10-member groups, one of which had an ITI of 25 s and the other a 90-s ITI. All other features of the procedure were the same as in Experiment 2.

RESULTS AND DISCUSSION

The left side of Figure 4 presents the probability of a win on the risky gamble (right roulette wheel) as a function of trials for the \$10 versus \$10,000 conditions. The top panel is based on choice when the ITI was 25 s, and the bottom panel is based on a 90-s ITI. The right side of the figure compares the 25-s and

90-s ITI conditions of this experiment. The top panel is based on the \$10 condition and the bottom panel is based on the \$10,000 condition.

The values of the Trial 10 data from Figure 4 were compared across the four groups (\$10 vs. \$10,000 × 25-s ITI vs. 90-s ITI) by a Kruskal-Wallis test. Significant between-group differences emerged, $H(3) = 14.03, p < .05$. Pairwise post hoc contrasts showed that the differences between groups at Trial 10 were significant for the two functions within each panel on the left side of Figure 4 but were not significant for functions from the right side of that figure.

These findings are consistent with those from Experiment 2 in demonstrating that when subjects know the number of trials in a session, ITI duration has little effect on risky choice. Also, these results are consistent with our framing-effect interpretation of the repeated-

gambles experiment: Whenever "income" is manipulated, either implicitly as in the study of Rachlin et al. (1986) or explicitly as in this experiment, risk aversion diminishes with increasing income levels.

GENERAL DISCUSSION

Rachlin et al. (1986) attempted to model Kahneman and Tversky's (1984) hypothetical-value and decision-weighting functions (see Figure 1) in terms of the matching equation (Equation 1). Modeling the value function was achieved easily because the matching equation, with $s < 1$, reproduces the value function's monotonic, negatively accelerated form. However, direct application of the matching equation to modeling the weighting function cannot be successful because its sigmoid form is incompatible with a simple power function. Rachlin et al. resolved this problem by creating the repeated-gambles experiment—a risky

Fig. 3. Mean probability of a win (number of white sectors) for the risky gamble (right roulette wheel) for each ITI group as a function of trials.

choice procedure in which the matching equation assumes a sigmoid form.

The Rachlin et al. (1986) model predicts the results obtained in the repeated-gambles procedure. Despite this success, there are rea-

Fig. 4. Mean probability of a win (number of white sectors) for the risky gamble (right roulette wheel) as a function of trials. The left panels show the effect of low versus high income levels for the 25-s (top panel) and 90-s (bottom panel) ITI groups. The right panels present the same data plotted to compare the effects of ITI duration on choice when both groups were given \$10 or \$10,000.

sons for questioning the premises of this model. Much of the empirical support for this model comes from the animal literature on self-control (e.g., Rachlin & Green, 1972). A common finding is that animals prefer small reinforcers after short delays over larger reinforcers after longer delays. Rachlin *et al.* see this impulsivity in the effects of ITI duration on risky choice. By virtue of its lower probability of reinforcement, the \$250 alternative has a longer mean interreinforcement time (or delay). Lengthening the ITI decreases the reinforcing value of the long-delay alternative, leading to an increased preference for the \$100 outcome.

Rachlin *et al.*'s (1986) model argues that their experiment permits subjects to have time preferences for money reinforcers. As a consequence, they discount the longer delay \$250 reinforcer more than the short-delay \$100 reinforcer in determining each reinforcer's present value. We question both of these expectations.

First, we consider the expectation that time preferences should be present in the repeated-gambles experiment. Imagine that each win in the repeated-gambles experiment involved actual cash payments. If subjects left the experiment before it was over with cash in hand in order to make a purchase, we would have a rationale for viewing this as a study in intertemporal choice. But if subjects stayed for all 10 trials, why would they have a time preference among the money sums earned? This would be similar to a preference for being paid \$10 per hour for morning work and \$5 per hour for afternoon work, as opposed to \$5 and \$10 per hour for these periods, even though your pay comes only at the end of a complete work day.

Even if this argument is flawed and time preferences can occur in the repeated-gambles procedure, we doubt that normal adults discount money reinforcers over time periods of 90 s. Economists measure money discount rates over months and years, and claim that people in industrialized countries have real discount rates of 3% per year. How can we reconcile these economic data with Rachlin *et al.*'s (1986) expectation that humans discount money at comparatively astronomic rates (see also Logue, Peña-Correal, Rodriguez, & Kabela, 1986)? Our explanation of the results of Experiment 1 is consistent not only with that study and that of Rachlin *et al.* (1986) but also

with the proposition that neither time preference nor discounting occurs in the repeated-gambles procedure. That is, subjects had an implicit expectation of how long a session might last. The higher trial density of the short-ITI group led those subjects to believe they would have more trials than the number expected by the long-ITI group. As a consequence, the short-ITI group could "afford" to take more risks toward increasing income, a fact reflected in their greater preference for the risky alternative.

We tested this interpretation in two related experiments. In the first (Experiment 2), we told two different ITI groups how many trials were in a session. Because there were no differences in what subjects in each group perceived to be the prospective income level offered during a session, we expected no between-group differences. There were none. In the next experiment (Experiment 3), we made a single alteration in its design: At the beginning of the session, half the subjects in each ITI group were given \$10,000 and the other half were given \$10. The results were consistent with our interpretation: ITI duration had no effect on choice, yet those given \$10,000 were more risk-seeking than those who were given \$10. These results support the conclusion that Rachlin *et al.*'s (1986) findings are more readily explained in terms of Kahneman and Tversky's (1984) concept of "mental accounting" than in terms of their own delay-based matching equation.

Since Skinner (1966), behavior analysts have emphasized that human action can be controlled in two ways: directly by response-reinforcer contingencies and indirectly by verbal descriptions of those contingencies. In the former case behavior is "contingency governed," whereas in the latter case it is "rule governed." This distinction permits operant principles to subsume many instances of behavior that have been viewed historically as within the cognitive-psychological domain. In this regard, Rachlin *et al.*'s (1986) model is parsimonious, because it attempts to explain human risky choice without considering it to be distinct from the contingency-based animal choice literature.

This parsimony is of significance even if one believes the Rachlin *et al.* (1986) model to be inadequate, because the failure of one model does not ensure the failure of alternative con-

tingency-based accounts. Nevertheless, we are not optimistic that a successful contingency model will be forthcoming, because instructions clearly affected risky choice in the present study, a result indicating that behavior is rule governed (Shimoff, Catania, & Matthews, 1981). For this reason, we believe a model that assumes risky choice is rule governed will be on surer ground. Although such a model necessarily would differ in kind from the contingency models that have been developed to account for animal schedule effects, it should benefit by being more easily related to cognitive interpretations of risky choice.

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