UNIVERSITY OF ALBERTA

Repeated gambles revisited: delay and probability in human choice

BY

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

DEPARTMENT OF PSYCHOLOGY

Edmonton, Alberta
Fall, 1992

ISBN 0-315-77123-2

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: Kevin Wilson

TITLE OF THESIS: Repeated gambles revisited: Delay and probability in human choice

DEGREE: Master of Science

YEAR THIS DEGREE GRANTED: Fall, 1992

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May 14, 1991

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Repeated gambles revisited: Delay and probability in human choice" submitted by Kevin Wilson in partial fulfillment of the requirements for the degree of Master of Science

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Abstract

Behavioral and cognitive psychologists study choice using different subjects, procedures and models. Kahneman and Tversky's (1984) cognitive account of non-normative choice proposes that humans employ non-linear transformations of probabilities and values. The matching law, a behavioral choice model, interprets allocation of responding on choice alternatives as proportional to reinforcment available on those alternatives. Rachlin, Logue, Gibbon and Frankel (1986) propose that Kahneman and Tversky's observations can be accounted for by the matching law if it is assumed that people treat probability as a delay to reward. Their model incorporating probability into the matching law also predicts that increasing intertrial interval (ITI) will increase risk-aversion. This prediction is supported by research in groups of subjects in long and short ITI conditions choose been roulette-style wheels with different amounts and probabilities of reward. Silberberg, Murray, Christensen and Asano (1988) claim that these results occur because subjects in different trial duration conditions expect different numbers of trials: what is observed is a framing effect, as described by Kahneman and Tversky, rather than an effect of delay to reward. They find no effect when subjects know how many trials to expect. The generality of this explanation was tested in the present study. When subjects were allowed to make 10 choices (as in the previous studies), no differences were observed, but subjects in 30 trial groups showed effects of trial

duration. These effects, however, are opposite to those predicted by Rachlin et al.'s formula: with longer trial duration, subjects become more risk-seeking. The failure of the model can be traced to errors in its mathematical development. Nonetheless, the results of this study suggest that human choice is sensitive to temporal parameters in the short term. Mazur's (1988) formula, in addition to providing a more intuitively valid description of delay discounting of reward value than the Rachlin et al. model, provides a possible avenue through which behavioral and cognitive approaches might be synthesized. A program of research based on Mazur's formula is described.

Acknowledgement

Dr. C. Donald Heth has been an exemplary mentor and role model. His insightful instruction and criticism, his intellectual eclecticism, his genuine concern for his students' well-being and his enthusiasm for science have been a boon and an inspiration. He has the balanced judgement of Solomon and patience that would make Job pale. I thank him for his encouragement and his guidance.

Thanks to my mother, my brother and my father for their support , encouragement , unflagging enthusiasm and semi-regular provision of operating funds.

Thanks to Robin Everall, Joan Hillson and Bob Barnet for their remarkable friendship. Special thanks to Judith Shedden for absolutely everything.

I'd like to thank the cleaning ladies for keeping me company and for putting up with the mess.

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Rachlin, Logue, Gibbon and Frankel (1986) noted that cognitive and behavioral models of choice seem to share little more than subject matter. Cognitive psychologists present human subjects with hypothetical choice situations and measure preference for alternatives varying in probability and amount of reward. Behavioral psychologists tend to measure animals' preference for manipulanda offering different amounts and schedules of reinforcement. Rachlin et al. proposed that a synthesis could be achieved between the two schools by relating probability to two variables of reinforcement: delay to and rate of reinforcement.

To explain how this might be accomplished, Rachlin et al. described the details of a representative cognitive study of choice. Kahneman and Tversky (1984) noted that humans, faced with choice involving risk, do not always select the alternative with the highest expected value. Consider, for example, choice between an 85% chance to win $1000 and a sure win of $800. Mathematically, the first alternative is preferable (.85 X $1000 = $850 for the first alternative vs. $800 for the second). In general, however, people choose the second alternative. Kahneman and Tversky attempted to account for this and similar deviations from "normative" solutions of choice problems.

In one study Kahneman and Tversky presented the results of an experiment in which subjects were asked to make two decisions (with percentage of people selecting each alternative in parentheses):

Problem 4 (N = 150): Imagine that you face the following pair of concurrent decisions. First examine both decisions, then indicate the options you prefer:

Decision (i) Choose between:

A.	a sure gain of $240	(84%)
B.	25% chance to gain $1000 and 75% chance to gain nothing	(16%)

Decision (ii) Choose between:

C.	a sure loss of $750	(13%)
D.	75% chance to lose $1000 25% chance to lose nothing	(87%)

Note that the expected outcomes for choices A and B are effectively identical, as are those for choices C and D. Nevertheless, people demonstrated a clear preference among these alternatives. Moreover, in the case of gains (A or B), the "sure thing" is the predominant choice; in the case of losses (C or D), the gamble was far more frequently chosen.

Part of Kahneman and Tversky's explanation for these results is based on the proposition that people transform amounts to be gained or lost according to a hypothetical value function presented in the top half of Figure 1. Note that the function is concave for gains and convex for losses and that the function is steeper for losses than for gains. The form of the function reflects Kahneman and Tversky's observation that as the size of a potential gain or loss increases, its subjective value is an increasingly small portion of its actual value. Kahneman and Tversky suggested that the concavity of the gains function is in part responsible for the "risk aversion" noted in people's solution of Decision (i) presented above. The larger gain loses more value after transformation by the value function than does the smaller gain. In terms of subjective value, 25% of a heavily reduced $1000 is worth less than 100% of a less heavily reduced $250. The same logic explains "risk seeking" behavior given Decision (ii), but risk seeking with losses is greater than risk avoidance with gains because of the steepness of the loss function.

Compounding these effects, are transformations of probability. These transformations are described by the hypothetical weighting function presented at the bottom of Figure 1. This function reflects people's tendency to overweight very low probabilities and to underweight moderate and high probabilities. So, for example, in Decision (ii) above, subjects will tend to seek risk because they face a loss, and their inclination to take a risk by selecting alternative D is magnified by an underweighting of the 75% chance of losing $1000.

A third factor influencing choice in Kahneman and Tversky's model is the context in which a choice occurs, which they refer to as the "frame". One example of a frame is any value to which a gain or a loss is compared. For example, a potential gain of $5 will seem large for someone whose current wealth is $10 but will seem small for someone currently holding $1000.

Despite its ability to account for a variety of examples of non-normative choice, Kahneman and Tversky's model lacks quantitative specificity: it allows for general predictions only. Moreover, the model remains largely descriptive: it provides no real indication of either the adaptive value of these patterns of choice behavior or of the mechanisms that might underlie them.

If the effects described by Kahneman and Tversky are accepted as genuinely reflecting human choice, it behooves behavioral psychologists to account for those effects in their own terms. Behavioral models of choice, mainly tested using data obtained from non-human animals, have emphasized analyses of how allocation of behavior reflects environmental conditions. A prominent example of this is the matching law (for a review see Davison and McCarthy, 1988), and it is into the matching law that Rachlin et al. (1986) proposed to incorporate parameters employed in cognitive research.

A generalized form of the matching law is described by:

$$\frac{B_1}{B_2} = \left(\frac{A_1}{A_2}\right)^a \left(\frac{R_1}{R_2}\right)^r \left(\frac{D_2}{D_1}\right)^d . \qquad (1)$$

B_1 and B_2 are response rates on two response alternatives, and A_x, R_x and D_x are the corresponding amounts of, rates of and delays to reinforcement on the two alternatives. The exponents a, r and d are indices of an individual's sensitivity to amount, rate and delay of reinforcement (with return maximized when sensitivities = 1). Thus, behavior directed at a particular response alternative varies directly with the amount and rate of reinforcement and inversely with the delay to reinforcement occurring on that alternative. The matching law already accommodates one of the variables deemed to be important in Kahneman and Tversky's model (amount of reinforcement = size of gain).

Rachlin et al. presented a means of incorporating the other variable, probability. They described a choice situation called the repeated gambles experiment. This involves the presentation of a roulette-style wheel with white and black sections (Figure 2). The probability of a subject winning when spinning the wheel is represented by the white portion of the wheel. If the wheel stops with the arrow pointing to a black section of the wheel, nothing is won. Rachlin et al. propose that the following formula describes the time expected to elapse before a subject's first win:

$$D = \frac{t+c}{p} - t, \qquad (2)$$

where D = expected delay from the initiation of a trial to the first win, t = intertrial interval (ITI), c = interval between choice and outcome and p = probability of a win. In calculating the time to the first win, t is subtracted because there is no ITI preceding the first trial. Over many spins, Rachlin et al. note, the rate of return would be

$$\frac{x}{p^{-1}(t+c)}, \qquad (3)$$

where x is the amount to be won. When p = 1/3, the rate of return is

$x/[3(t+c)]$; if $p = 1/2$, the rate is $x/[2(t+c)]$. Higher probabilities, therefore, result in higher rates of return.

By reinterpreting probability as a delay to gain or reinforcement in the manner described above, it becomes possible to incorporate probability into the matching law. Rachlin et al. assume that "rate of reinforcement is perfectly confounded with delay." Delay is then equal to the inverse of reinforcement rate (i.e., $R_1 = 1/D_1$ and $R_2 = 1/D_2$). Equation 1 becomes:

$$\frac{B_1}{B_2} = \left(\frac{A_1}{A_2}\right)^a \left(\frac{D_2}{D_1}\right)^r \left(\frac{D_2}{D_1}\right)^d = \left(\frac{A_1}{A_2}\right)^a \left(\frac{D_2}{D_1}\right)^{r+d} \tag{4}$$

When Equation 2 is substituted for each of D_1 and D_2, the result is

$$\frac{B_1}{B_2} = \left(\frac{A_1}{A_2}\right)^a \left(\frac{\frac{t_2+c_2}{p_2} - t_2}{\frac{t_1+c_1}{p_1} - t_1}\right)^{r+d}, \tag{5}$$

which, simplified, becomes

$$\frac{B_1}{B_2} = \left(\frac{A_1}{A_2}\right)^a \left(\frac{p_1(t_2 + c_2 - t_2p_2)}{p_2(t_1+c_1 - t_1p_1)}\right)^{r+d}. \tag{6}$$

If $c_1=c_2=c$ (the time between choice and the outcome of choice is the same for both alternatives) and $t_1=t_2=1$ (the ITI for both alternative is the same and is equal to one time unit) this equation becomes

$$\frac{B_1}{B_2} = \left(\frac{A_1}{A_2}\right)^a \left(\frac{p_1(1 + c - p_2)}{p_2(1 + c - p_1)}\right)^{r+d} \tag{7}$$

Rachlin et al. proposed that this last equation reflects the two effects of probability on choice between alternatives (the effects on overall rate of reinforcement and on delay) when those effects are confounded. This confounding of effects, they claimed, is typical of cognitive models.

An important feature of this new model is that it approximates features of the functions described by Kahneman and Tversky. The value function is replicated by $(A_1/A_2)^{sa}$ for some values of *sa* less than 1. Rachlin et al. also showed that their model could account for the weighting function. Setting $p_2 = 1.0$, $c = 0.2$ and $A_1 = A_2$, for example, Equation 7 becomes

$$\frac{B_1}{B_2} = \left(\frac{0.2p_1}{1.2\text{-}p_1}\right)^{r+d}. \qquad (8)$$

With some values of sr+sd less than one, the function obtained from this formula (by varying p_1) approximates Kahneman and Tversky's weighting function.

The new model makes an additional prediction not accounted for by the Kahneman and Tversky model. In order to demonstrate this prediction, Rachlin et al. proposed an experiment in which two wheels were employed. Each wheel had 18 sections that could be colored black or white. One wheel, which had a fixed number of white sections (17), provided $100 if a subject chose it and won. The second wheel provided $250 for a win, and the number of white sections on the second wheel for a given trial was contingent on the choice on the preceding trial. If the $100 wheel was selected, one of the black sections of the $250 wheel became white (increasing its probability of providing a win). If the $250 wheel was selected, one of the white sections became black (decreasing its probability of a win). Thus, if subjects expressed a preference for the gamble on the $100 wheel by selecting that alternative, the $250 wheel was made a more attractive gamble. If, on the other hand, the $250 wheel was preferred, it was made a less attractive gamble. Over several trials, the probability on the $250 wheel was expected to reach a point of equilibrium at which the $100 and $250 wheels were rated as equivalent gambles.

In this situation, A_1 (the amount to be won on the first wheel) was $100 and A_2 is $250. The value of p_1 was approximately 1. In their example, Rachlin et al. assumed that the trial durations, c_1 and c_2, were 5 s, the intertrial intervals (ITIs) were the same ($t_1 = t_2 = t$), and $a = r+d = 1$. Substituting these values into the Equation 7, Rachlin et al. proposed that if $t = 0$, then $p_2 = .4$ at equilibrium. As t increases, p_2 approaches 1. Increases in ITI, therefore, result in an an increase in risk avoidance.

Rachlin et al. conducted an experiment in which two groups of subjects were given 10 opportunities to choose between two wheels using the parameters described above. Starting probability on the $250 wheel was 7/18 (which made the expected values of the two wheels roughly equivalent at the start of the experiment). For one group, trials were completed as quickly as possible (an average of 30 s per trial, 5 min per session). For the other group, the experimenter removed the two wheels from the table in front of the subjects for 1.5 min after each trial.

The results of this experiment confirmed the additional hypothesis of the new model. Subjects in the long ITI group were significantly more risk averse than were subjects in the short ITI group. Rachlin et al. argued that their model is more parsimonious than the cognitive theory because it merges two sets of data successfully, thereby accounting for a wider variety of choice phenomena. They also felt that their model was more quantitatively precise than the cognitive model.

Silberberg, Murray, Christensen and Asano (1988) presented an alternative explanation for the results of the repeated gambles experiment, informed by cognitive perspectives on choice. As previously described, Kahneman and Tversky (1984) suggested that people evaluate gambles in relative terms. Silberberg et al. propose that it is this sort of framing effect, some effect of context, that accounts for the Rachlin results.

Silberberg et al. suggested that all subjects in the Rachlin experiment anticipated sessions of a certain length (presumably as a function of their expectations related to research participation). Short-ITI subjects, therefore, expected a greater number of trials than the long-ITI subjects. This translates into a greater anticipated number of opportunities to win for short-ITI subjects. Any single opportunity to win is less important for them than for long-ITI subjects (Silberberg et al. suggest that short-ITI subjects "perceive themselves as having less to gain in choosing either alternative than do the long-ITI subjects.") Silberberg et al. show how this explanation can be rendered in terms of Kahneman & Tversky's hypothetical value function. Referring to the "gains" axis in the top half of Figure 1, they propose that the $100 and $250 points would be placed closer to the origin for the short-ITI group than they would for the long-ITI group. Short-ITI subjects, therefore, will be less risk averse.

In their first experiment, Silberberg et al. tested the effects of these modifications by attempting a replication of the Rachlin et al. experiment. They modified the procedure in two important respects: a) trials were presented by computer, rather than by an experimenter; b) the first trial began with a choice between wheels for half of the 25-s and the 90-s ITI subjects (Trial groups) and with an ITI for the other half (ITI groups). Despite the changes, they obtained the same results observed by Rachlin et al.: the 25-s ITI group were less risk-averse than the 90-s ITI group, regardless of whether the first trial began with a selection or with an ITI.

In order to test their framing effect hypothesis, Silberberg et al. told subjects before each session began in their second experiment how many opportunities to choose they would have; they also indicated how many trials were remaining during each ITI. Since subjects in all groups now shared the same expectation of the amount to be won, Silberberg et al. predicted that no between-groups differences would be observed. The results confirmed this prediction: the data obtained indicated virtually no difference in risk aversion between the 25-s and 90-s ITI groups.

In contrast with the implied frame manipulation demonstrated in the last experiment, Silberberg et al. proposed that a similar effect could be obtained by explicitly manipulating the frame. In a third experiment, subjects in the two ITI groups were additionally divided into two groups who were told at the outset of the experiment that they began the session with either $10 or $10,000. Silberberg et al. predicted that the $10,000 subjects would be less risk averse, regardless of which ITI group they were in. This prediction was confirmed.

Silberberg et al. noted that choice behavior may be "contingency governed" – directed by response-reinforcer contingencies – or "rule governed" – directed by verbal descriptions of contingencies. The Rachlin model, they suggested, assumes that human risky choice can be explained as an example of contingency-based choice, like that described in the animal literature. Silberberg et al. acknowledge the value of devising a single model that explains human and animal choice. They note, moreover, that the failure of the Rachlin model did not preclude the possibility that a contingency-based model capable of doing so would be developed.

They were not hopeful, however. Referring to their own data, they concluded that choice behavior must be rule governed because instructions influenced choice in their experiment, amongst others (e.g., Shimoff, Catania and Matthews, 1981). Models that assume that risky choice is rule governed will therefore be more successful. Silberberg et al. suggest these models would "benefit by being more easily related to cognitive interpretations of risky choice."

It is not clear that Silberberg et al. present enough evidence to warrant dismissing entirely the effect of contingencies on human choice. Silberberg et al. argue that instructions affect human choice, therefore contingencies can be ignored. Their argument is not compelling: it hinges on the view that contingencies and "rules" are distinct, which has not been demonstrated. It seems reasonable to interpret contingencies *as* rules, rules that are inferred through experience with the environment and adhered to based on that experience. If by "rules" Silberberg et al. mean verbal instructions, then the fact that rules have an effect on choice is not problematic for a behavioral explanation of choice. A verbal rule: 1) describes a contingency that a subject can adhere to with an absolute degree of certainty until such time that the environment contradicts the rule, or 2) sets the context in which the outcomes of contingencies occurring on choice alternatives are evaluated.

Of more immediate importance is the suggestion that humans are not sensitive to economic factors in the very short term. Citing economists, Silberberg et al. claim that people discount money at a rate of 3% per year, a rate that is unlikely to produce a difference when ITIs are varied by a few seconds. The conclusions Silberberg et al. draw have important ramifications for the study of human choice behavior. If human risky choice behavior is insulated against the effects of contingencies, then research on animals, which suggests that animals are strongly influenced by rate and time factors, may have limited applicability in the human domain.

In view of the import of these conclusions, it seems reasonable to test Silberberg et al.'s explanation more rigorously. As Silberberg et al. note, the Rachlin et al. study is an unusual behavioral study in terms of the brevity of its sessions (10 trials, 5 or 20 min duration). Perhaps the predictions obtained from the new formula are still valid, but a longer session is required for the effects to emerge. If human choice is not influenced by time preferences or time discounting, there should still be no between-groups differences in risk-aversion if the number of trials is increased.

The present experiment is similar to those conducted by Rachlin et al. and Silberberg et al. Subjects were required to make a number of selections between two alternatives. One alternative offered a small reward delivered with a high, fixed probability. The other alternative offered a large reward, but with a probability of winning was adjusted over trials. The purpose of the the adjustment was to determine the probability required to make the large reward an equally attractive alternative as the small amount delivered with a very high probability. In this experiment, as in the two previous studies, half of the subjects experienced long trial duration trials and the other half experienced short trial duration trials. In the earlier studies, all subjects were given 10 trials. In this experiment, half of the subjects in each trial duration group were given 10 trials and the other half were given 30. The primary objective is to determine whether the pattern of risky wheel preference predicted by Rachlin et al. emerges for subjects in the groups experiencing more trials.

Several minor procedural variations were also employed. Rachlin et al. and Silberberg et al. manipulated delay of outcome by including a long intertrial interval during which subjects were required to wait. The present experiment removed this intrusive event and manipulated delay by increasing the duration of a trial. In addition, side of risky wheel presentation is selected randomly to preclude the possibility that subjects develop a simple side preference.

Method

General procedure

In the repeated gambles experiment, subjects are asked to choose between two alternatives over a number of trials. Alternative one offers a small, imaginary money reward delivered with a high, fixed probability. Alternative two offers a large reward delivered with a probability that is initially low or moderate. The probability associated with alternative two is adjusted after each of the subject's choices. If a subject chooses alternative one, the probability associated with alternative two is increased slightly in order to make alternative two more attractive. Conversely, choice of alternative two is followed by a small reduction in that alternative's associated probability. It is expected that the second alternative's probability will, after many choices, reach a level making the two alternatives (small nearly certain reward on alternative one vs. large risky reward on alternative two) equally attractive gambles for the subject.

In this experiment, the alternatives were represented by two circles (wheels). Each wheel had a band on its perimeter. One portion of the band was colored white and the remainder was black (see Figure 2). The proportion of white on a wheel's band indicated the probability of winning the associated reward. For example, if one third of the band were colored white, then the probability of winning the associated alternative's reward was 1/3. Each band was divided into 18 unmarked sections of equal size. A change in the probability associated with an alternative was signalled by a change in color of a section on the appropriate wheel. If, for example, the probability was to be reduced, one previously white section became black. In this experiment, one wheel offered an almost certain probability of success and paid $100 dollars (the sure-thing wheel). The other wheel had a variable probability of providing a win and paid $250 dollars (the risky wheel). After a subject selected a wheel, the wheel would appear to spin for a fixed period of time before it indicated whether a win had occurred. The duration of spin determines the delay to reward.

Dependent variables

The present experiment was intended to clarify the results of two previous repeated gambles experiments. The methodologies employed in the earlier studies were similar, but different dependent measures were analyzed. Rachlin et al. used, as their primary measure, a subject's total number of risky wheel choices as a measure of risky wheel preference: stronger preference is reflected by [illegible]ger number of choices. More risky wheel choices, however, also result in a smaller number of risky wheel white sections. Silberberg et al. chose to use the final number of risky wheel white sections (hereafter referred to as risky wheel endpoint) as their measure of preference.

Number of risky wheel choices and risky wheel endpoint are related, but they are not equivalent. As an example, consider a situation in which two subjects begin their sessions with a different number of white sections on the risky wheel (i.e., different risky wheel starting probability). In keeping with parameters used in this experiment, assume that one subject's risky wheel starting probability is 4/18 and the other subject's is 10/18. If both subjects choose the risky wheel seven times over ten trials, their final risky wheel probabilities will be 0/18 and 4/18. If number of risky wheel choices is used as the measure of preference, the subjects show equal preference. If risky wheel endpoint is the measure of preference, the subjects have demonstrated a difference in preference.

The question of which measure is more meaningful hinges on whether or not the probability on the risky wheel at the session's end is the value that the subject requires to make the two alternatives equivalent gambles. If so, then the difference indicated by the risky wheel endpoint is likely informative. If not, risky wheel probability will continue to change. In that case, it is possible that the number of risky wheel choices will be more informative. What has been shown in the current example is that, over ten trials, the subjects showed equal risky wheel preference, insofar as they chose the risky wheel the same number of times.

To summarize, previous studies have employed different measures of preference. In addition, each of the two measures previously used may provide information not supplied by the other. In the present experiment, therefore, both indices of preference, the number of risky wheel choices and risky wheel endpoint, were examined as measures of preference.

Independent variables

Three independent variables were manipulated in this experiment in a 2 x 2 x 2 between subjects design. The first factor was duration of spin (30 or 90 seconds). This is comparable to the trial duration parameter in the Rachlin and Silberberg studies. The second factor was number of trials (10 or 30). The 10 trial condition was intended to replicate the procedure used in the two previous studies; the 30 trial condition was introduced so that the generality of the findings in the 10 trial condition could be assessed. The third factor was the starting probability on the risky wheel (high or low). This manipulation was added as a control: we wanted to assess whether subjects' choices were influenced by the starting probability on the risky wheel. First trial probability for the risky wheel was 10/18 for subjects in high groups, 4/18 for subjects in low groups.

The primary aim of this experiment was to determine whether a larger number of trials than used by Silberberg et al. would result in a difference in preference between the 30 and 90 s groups as measured either by risky wheel endpoint or proportion of choices on the risky wheel. Note that number of risky wheel choices must be changed to a proportion because some subjects receive ten trials and others receive 30. A secondary aim was to assess whether the starting probability on the risky wheel had any effect on preference.

Subjects

Sixty-five subjects (41 females, 23 males) were employed in this experiment. All were undergraduate students who participated to fulfil an introductory psychology course requirement. Subjects were assigned randomly to conditions.

Apparatus

All sessions were conducted in a small room. Instructions and trials were presented on a Macintosh computer.

Procedure

Instructions At the beginning of each 10 trial session, the following instructions were presented on the computer monitor, accompanied by a diagram depicting a hypothetical trial situation:

> In this experiment you will be asked to choose between pairs of imaginary gambles: your task is to try to 'win' as much money as possible. You will be asked to choose between pairs of roulette wheels like the ones you see pictured below. Notice that the wheels have different amounts of white and black on them and that different dollar amounts appear beneath them.
>
> A pointer will appear above the wheel that you select on each trial. If you were to choose the wheel marked 'Z' below and the wheel stopped with the pointer pointing to a white section of the wheel, then you would 'win' $100. If you were to choose to spin the wheel marked '/' below and the wheel stopped with the pointer pointing to the white section of the wheel, then you would 'win' $250.
>
> If you choose either wheel and the wheel stopped with the pointer pointing to a black part of the wheel, you would win nothing.
>
> To choose the gamble that you prefer, press the letter associated with that gamble (e.g.: press 'Z' to choose the alternative on the left, '/' to choose the alternative on the

right). The wheel you choose will spin as soon as you press a key indicating your choice. You are not required to stop the wheels: they will slow down and come to a stop by themselves.

When a pair of wheels is presented at the beginning of a trial, you must choose one of the wheels within 10 seconds. After 5 seconds, you will hear a beep and the computer will remind you that you have only 5 seconds left to select on of the gambles. In order to make it easier to respond quickly, you might want to keep on finger close to each of the response keys (next to the shift keys on either side of the keyboard).

There will be 10 trials in total.

Remember that you should try to 'win' as much money as you can. If you have any questions, please feel free to ask the researcher now.

Please be advised that if at any time you do not wish to continue in this experiment, you may stop without penalty.

Instructions for 30 trial sessions were the same, except that they indicated that there would be 30 trials.

Trials Each trial began with the presentation of the sure-thing and risky wheels side by side against a dark grey background on the computer monitor. The wheels were approximately 4.5 cm in diameter with a light gray center approximately 3.5 cm in diameter.

Underneath each wheel was a label indicating the amount that could be won by spinning that wheel ($100 for the sure-thing wheel, $250 for the risky wheel).

The 0.5 cm perimeter of each wheel had one black and one white sector. The size of a wheel's white sector represented the probability of winning with that wheel. The perimeter of the sure-thing wheel had 17 of 18 sections colored white at all times in all conditions. The risky wheel began with 4 of 18 sections white for subjects in the low starting probability conditions and with 10 of 18 sections white for subjects in the high starting probability conditions. The number of white sections on the risky wheel varied as described below. There were no markings on the wheels indicating the number of sections into which each wheel was divided.

Whether the risky wheel or the sure-thing wheel would appear on the right was randomly determined for each trial. The character "Z" appeared in the center of the left wheel, and the character "/" appeared in the center of the right wheel.

At the beginning of each trial the message "Which gamble do you chose (Z or /)?" appeared at the bottom of the monitor. The subject was then required to press one of the response keys. If neither key was pressed within 5 seconds, a tone was played and the message at bottom of the screen was replaced with the text "Please choose within 5 seconds (Z or /)?". If no response occurred in the next five seconds, the session was terminated.

Keypresses on the "Z" and "/" keys selected the left and right wheels respectively. If a response was successfully made, the text at the bottom of the screen, the wheel not selected, the two dollar amount labels and the "Z" and "/" labels were removed from the screen. A small elongated triangle appeared above the selected wheel with its tip touching the topmost point on the wheel. At the same time the selected wheel would appear to begin spinning.

Wheel animation involved the use of 36 frames, each depicting one part of a sequence in which the wheel image was rotated 10 degrees at a time. The initial speed of rotation was the same in all conditions. The wheel decelerated at a constant rate reflecting the spin duration of the subject's experimental condition. For subjects in 30 second spin duration conditions for example, the selected wheel's rotation decelerated at a rate that would make the wheel come to a stop after 30 seconds.

If the tip of the triangle was pointing to a white portion of the selected wheel when it stopped rotating, then the message "You won. Total winnings: $X", where "X" was the number of dollars the subject had won so far. Prior to the message being displayed, the subjects record of winnings had been increased by $250 (if the risky wheel had been chosen) or $100 (if the sure-thing wheel had been chosen). If the indicated portion of the wheel was black, the message "You lost. Total winnings: $X" appeared. The outcome message was displayed for 2 seconds.

On each trial after the first, the probability of a win on the risky wheel was determined by the choice on the previous trial. If the risky wheel had been selected, the probability of a win on the risky wheel on the following trial was decreased by changing one of the white sections adjoining the black section of the wheel from white to black. If the sure-thing wheel had been chosen, the probability of a win on the risky wheel for the following trial was increased by changing one of the black sections to white. Trials proceeded in this manner until 10 or 30 trials had been completed depending on the condition to which a subject had been assigned.

Results

Overview

Failing to observe a delay effect with 10 trial sessions, Silberberg et al. concluded that temporal factors have a minimal effect on human choice. The purpose of the present study was to test this conclusion more rigorously. The specific intent was to see if differences emerge between comparable 30 and 90 s trial duration groups after a larger number of trials. "Comparable trial duration groups" refers to groups differing only in terms of trial duration (and having, therefore, the same number of trials and the same starting probability).

Although the dependent measures used in this experiment are risky wheel choice proportion and risky wheel endpoint, both Rachlin et al. and Silberberg et al. present trial by trial means of the number of risky wheel white sections for each of their groups. Figure 3 presents the current data in the same way to allow a visual comparison of the three studies. Lower numbers of white sections are assumed to reflect a greater degree of risk seeking. The filled symbols represents data for subjects in conditions most similar to those experienced by subjects in the two previous studies; empty symbols represent data from the conditions in which subjects experienced a larger number of trials.

Endpoint data

Risky wheel endpoint data is presented in Table 1. Differences between the means of comparable 10 trial groups are small. In both the low and high conditions, the difference between trial duration groups is 0.5 white sections (compared to a possible maximum difference of 18). The differences in means for comparable 30 trial groups are relatively large: a difference of 2.4 white sections between trial duration groups with low starting probabilities, 1.8 white sections for the high starting probably groups. Both 90 s/30 trial groups exhibit a lower endpoint than their 30 s counterparts. The 10 trial data is less consistent: the 90 s/10 trial/high group has a higher endpoint than its 30 s counterpart.

The larger differences between comparable 30 trial groups relative to 10 trial groups suggests the possibility of a trial duration by trial number interaction – no effect of trial duration for 10 trial subjects but an influence of duration risky wheel choice for 30 trial subjects. The absence of a trial duration effect for the 10 trial subjects would replicate the Silberberg et al. results, but the presence of a similar effect for the 30 trial subjects would be inconsistent with both of the earlier studies. In particular, the direction of the effect would be opposite to that predicted by Rachlin et al. The long trial duration groups have fewer risky wheel white sections at session's end, indicating that they were more risk-seeking than their short trial duration counterparts.

Three way analysis of variance on the endpoint data does not confirm the presence of a trial duration by trial number interaction ($F_{1,56} = 2.2, p = .14$). There were, likewise, no effects due to trial duration ($F_{1,56} = 2.3, p = .14$) nor number of trials ($F_{1,56} = .002, p = .96$) nor other interaction. Statistical analysis of the endpoint data therefore supports Silberberg et al.'s prediction of no effect due to trial duration.

It should also be noted that, in all cases, the mean number of risky wheel white sections is higher for high starting probability groups than for corresponding low starting probability groups. Differences range from 3.8 to 4.8 white sections. Three-way analysis of variance confirms the presence of a strong main effect due to risky wheel starting probability ($F_{1,56} = 28.5, p = .0001$). Interactions involving this variable were not significant. If the final probability on the risky wheel – equal to its number of white sections divided by 18 – represents the probability required to make the two alternatives equally attractive, one might expect that the final number of white sections would be the same for groups differing only in starting probability. The observed outcome suggests that choice between the two alternatives is not governed only by the probabilities and reward sizes associated with the two wheels but also with the broader context in which choice takes place.

Proportion data

The mean and standard deviation for the second dependent measure – proportion of risky wheel choices – are presented in Figure 4 and Table 2. Means lower than 0.5 indicate overall preference for the sure thing wheel, whereas means higher than 0.5 indicate overall preference for the risky wheel. Differences between comparable trial duration groups are larger for 30 trials subjects (high starting probability: .029; low starting probability: .060) than for 10 trial subjects (both starting probability conditions: .025). As with the endpoint data, subjects in 90 s conditions show a greater preference for the risky wheel (or a smaller sure thing wheel) preference than their 30 s counterparts. Results for at least one of the 30 trial pairs again present the possiblity that differences between 30 s and 90 s groups appear when a greater number of trials is involved.

The proportion data cannot be analyzed in the same manner as the endpoint data. The 10 trial group data is more variable than the data for the 30 trial groups. This was confirmed with Hartley's F_{max} test for homogeneity of variance ($F_{max} = 40.0, p < .01$). It is necessary, therefore, to analyze data from the two trial number conditions separately. There are no significant differences in variance within the 10 trial group (F_{max} = 1.8, $p > .05$) or the 30 trial group (F_{max} = 7.7, $p > .05$).

Analysis of variance suggests no effect of duration for subjects in the 10 trial condition ($F_{1,38}$ = 0, p = 1.0), replicating the findings of Silberberg et al. Subjects in the 30 trial condition, however, do demonstrate an effect of trial duration on allocation of choice ($F_{1,38}$ = 5.5, $p < .03$). Thus, in contrast to the results obtained using endpoint data, choice proportion data indicates that an effect of trial duration occurs for subjects exposed to a greater number of trials. Subjects in 90 s/30 trial conditions are more risk seeking than their 30 s counterparts, a finding contrary to the prediction of Silberberg et al. but opposite in direction to the prediction of Rachlin et al..

There is no effect of starting probability for the 10 trial groups ($F_{1,38}$ = 3.3, $p > .07$). The proportion of risky choices made by subjects in the 30 trial groups, however, indicates an effect of risky wheel starting probability ($F_{1,38}$ = 9.1, $p < .01$). There is no interaction between trial duration and starting probability in either the 10 trial ($F_{1,38}$ = .273, $p > .6$) or the 30 trial case ($F_{1,38}$ = .61, p = .44).

These results must be interpreted with some caution, however. If two subjects start with different risky wheel probabilities but make the same number of risky wheel choices, they have demonstrated the same risky wheel preference in terms of choice proportion. Despite making the same number of risky wheel choices, however, they have indicated that they require different risky wheel probabilities in order to bring the two alternatives into equilibrium. In must be noted, therefore, that proportion of risky wheel choice may not definitively reveal effects due to starting probability. Statistical analysis of starting probability based on risky wheel choice proportion can likely not be interpreted in a meaningful way in terms of the aims of this experiment.

Other measures

In view of the support (albeit limited) for the emergence of an effect of trial duration for subjects in the 30 trial groups, it is necessary to consider the possibility that groups varied in terms of some variable other than duration not controlled in the experiment. It is possible that subjects in a particular group took more or less time to respond than subjects in other groups. If time taken to respond contributes determination of rate of return, interpretation of the results would be compromised by a systematic variation in response times between groups. Response times are not likely to be responsible for the results obtained in this study (mean response times appear in Table 3). There is no effect of response time amongst the 10 trial groups ($F_{1,38}$ = .57, p = .46) or the 30 trial groups ($F_{1,38}$ = .3.5, p = .07). Although this latter result approaches significance, the mean difference between the 30 trial 90 s and 30 s groups is less than half a second, which is unlikely to have had any impact considered relative to total trial duration. There were also no reaction time effects related to starting probability (10 trials: $F_{1,38} = 3.3$, $p = .08$; 30 trials: $F_{1,38} = .54$, $p = .47$) or to an interaction between duration and starting probability (10 trials: $F_{1,38} = 3.0$, $p = .09$; 30 trials: $F_{1,38} = .42$, $p = .52$).

The ratio of rates of return from each wheel (i.e., the total amount won on that wheel divided by total amount of time that the wheel was spinning during a session) was compared (ratios of risky vs. sure-thing rates of return are presented in Table 4). There are no effects of relative rate of return due to duration (10 trials: $F_{1,38} = .001$, $p = .98$; 30 trials: $F_{1,38} = .25$, $p = .62$) or to an interaction of duration and starting probability (10 trials: $F_{1,38} = .36$, $p = .56$; 30 trials: $F_{1,38} = .062$, $p = .81$). There is, predictably, an effect due to starting probability (10 trials: $F_{1,38} = 9.4$, $p < .01$; 30 trials: $F_{1,38} = 14.6$, $p < .001$). Note, however, that this effect cannot account for the difference in risky wheel preference between low and high starting probability groups. High starting probability groups obtained a higher rate of return from the risky wheel but selected it less frequently than low starting probability groups.

Discussion

The results indicate that human choice in the risky gambles experiment may be sensitive to trial duration. Both measures -- the number of white sections on the risky wheel at the end of the session and the proportion of times that the risky wheel was chosen --

indicated that subjects chose the risky wheel more when trials lasted longer. Only the second measure was significant, however, suggesting that either endpoint is a less sensitive measure of preference or that subjects had not attained equilibrium in all conditions.

Silberberg et al. failed to find an effect of trial duration after ten trials when the controlled for the subjects' expectations of session duration. By extension, the argued that risky choice was insensititve to contingency based effects such as delay of reinforcement. The present results suggest that their failure to find an effect was due to an insufficient number of trials. If so, this study re-establishes the importance of contingency-based variables to any theoretical treatment of risky decision making that combines cognitive and behavioral models.

The results from high vs. low probability groups also lends support to the notion that choice is sensitive to the effect of "frames", in agreement with the view of Silberberg et al.. According to this view, choice can be influenced by the context in which choice takes place and not by simple economic factors. In their Experiment 3, Silberberg et al. showed that subjects are more risky seeking when told that they start the experiment with an imaginary $1000 relative to subjects starting with an imaginary $10. In the present experiment, the attractiveness of a particular risky wheel probability seems to have been influenced by the initial probability on that wheel.

An interpretation of this outcome on the basis of a framing effect might suggest that subjects evaluated risky wheel probability relative to the initial probability. High starting probability subjects would, therefore, find a given low probability less attractive than low starting probability subjects. The precise cause of the difference in results obtained for the low- and high-starting-probability groups requires further investigation.

Although the results indicate that temporal factors affect human choice, they are problematic for Rachlin et al.'s model. That model predicts an increase in risk aversion with increasing trial duration. In this experiment, however, longer trial durations resulted in more risk seeking. The model's failure may lie in the logic of its derivation. The effects of probability are modelled in Equation 2 ($D = (t+c)/p - t$). However, Rachlin et al. proposed that D represents the delay to only the first win. This was underlined in two ways using examples with a probability of winning of 1/3.First, Rachlin et al. emphasize their feeling that it is the ITI *preceding* a choice that is applied, in time-accounting terms, to that choice. They claim that "if the first spin occurred only after an initial t-s interval, the expected delay would be $3(t + c)$". That is, no correction would be made for the lack of an ITI preceding the first trial. Second, they imply that the long run rate of return is not influenced by a missing ITI preceding the first trial after a win, stating that "over a long series of spins, the rate at which money is given to the subject would be $x/[3(t + c)]$"

Given these stipulations, Rachlin et al. were in error when they substituted Equation 2 [$p^{-1}(t + c) - t$], which corrects for the absent initial ITI, rather than the denominator of Equation 3 [$p^{-1}(t + c)$] into Equation 4. If the later formula is substituted into Equation 4, a result different from that described by Rachlin et al. is obtained:

$$\frac{B_1}{B_2}=\left(\frac{A_1}{A_2}\right)^a\left(\frac{\frac{t_2+c_2}{p_2}}{\frac{t_1+c_1}{p_1}}\right)^{r+d}, \tag{9}$$

which, simplified, is

$$\frac{B_1}{B_2}=\left(\frac{A_1}{A_2}\right)^a\left(\frac{p_1(t_2+c_2)}{p_2(t_1+c_1)}\right)^{r+d}. \tag{10}$$

If it is assumed, following Rachlin et al., that $t_2=t_1=1$ and $c_2=c_1=c$, the result is

$$\frac{B_1}{B_2}=\left(\frac{A_1}{A_2}\right)^a\left(\frac{p_1(1+c)}{p_2(1+c)}\right)^{r+d}. \tag{11}$$

Equation 11 simplifies to

$$\frac{B_1}{B_2}=\left(\frac{A_1}{A_2}\right)^a\left(\frac{p_1}{p_2}\right)^{r+d}. \tag{12}$$

Equation 12 predicts that choice between the two alternatives can be predicted on the basis of amount and probability of reward, without reference to delay.

Liberally adapting Rachlin et al.'s argument, it might be that delay to a win will *always* be equal to $p^{-1}(t + c) - t$. In other words, the ITI following a win is not applied to the alternative on which the win occurred. Subtracting t will always be appropriate. It would then be necessary to argue that it is the ITI *following* a choice that is associated with the choice alternative. (This ignores the issue of what happens to the "extra" ITIs, if anything). This argument does not rehabilitate the model. Suppose, for instance, that ITI = 0. Equation 2 then becomes

$$D = \frac{c}{p}, \tag{13}$$

and the result for the model is again Equation 12. According to this model, risk aversion is affected by changes in ITI but not by changes in trial duration.

This seems improbable. Mazur (1989) found that Equation 12 did not describe data he obtained using pigeons that chose between reinforcers delivered with varying probability and reinforcers delivered after a delay. Consequently, an acceptable theoretical model regarding the effects of delay is still lacking. But, despite its predictive inadequacy, Equation 2 continues to be used as a means to incorporate probability into behavioral models of choice (Rachlin, Castrogiovanni & Cross, 1987; Rachlin, Raineri & Cross, 1991).

An additional problem with the Rachlin et al. model is that it makes assumptions about how components of trial duration are applied to the time accounts of one alternative or another. Some of those assumptions have to do with the role of ITI. Mazur has demonstrated that the value of a particular reinforcer is related to the total time spent in the presence of stimuli associated with the alternative on which that reinforcer is obtained (Mazur, 1989, 1991). ITI, he suggests, has a small or no influence. According to this view, the important temporal variable in this experiment is the duration for which a wheel spins after it has been selected.

Quite apart from its inability to account for the present results, the failure of Rachlin et al.'s model leaves open the issue of whether a behavioral model can account for the data described by Kahneman and Tversky. Future research should probably not rely too heavily on the repeated gambles experiment. It is not sufficiently similar to cognitive experiments to produce data directly comparable to the results of Kahneman and Tversky. Choice may be influenced not only by stated probabilities but also by contingencies. The present procedure is also not a good one relative to other behavioral studies. There are too few trials and contingencies may be confounded with the stated wheel probabilities.

Additional research is required to confirm or refute the existence of the trial duration effect that was demonstrated in this study. If the results are confirmed, it will be necessary to develop a new model to account for the results. Future research, however, should proceed in a conservative, step-wise fashion, initially testing new models' predictive value in situations closer in form to typical behavioral experiments and proceeding towards experiments more closely resembling the work of Kahneman and Tversky.

In most behavioral experiments, parameters like rate, delay and probability of reward have to be inferred over a large number of trials during which preference for one alternative or another is assumed to become stable. The first step, then, would be to determine whether a new model correctly predicts indifference points between certain long-delay and probabilistic short-delay alternatives in sessions with a large number of opportunities to experience both alternatives. The probabilities associated with the alternatives would not be verbally or (as in this experiment) graphically described. Although Mazur's (1987) adjusting procedure is attractive from the point of view of efficiency, a more conservative approach requires that the utility of the formula be assessed with fixed probabilities and delays, perhaps testing for effects between subjects. The amounts, delays and probabilities to be employed would be determined using a model's predictive formulae. Analysis of the results would involve calculation of reinforcer value based on actual delay probabilities.

It should be noted that Rodriguez and Logue (1988) have shown that subjects' sensitivity to the effects of delay can be increased by decrementing winnings over time and providing relevant feedback to subjects. This seems a reasonable (and perhaps necessary) modification of experiments of this type.

If a new model is shown to describe choice in the simple situation described above, it would be worthwhile to test it when a modified version of Mazur's adjusting procedure is used. In this experiment, as in the repeated gambles experiment, a parameter would be adjusted, contingent on subjects' choices, in order to bring two alternatives into equilibrium (i.e., give them the same subjective value). Either the probability of the probabilistic alternative or the delay of the delayed alternative could be adjusted while the other is held constant. In either case, if the indifference points obtained in this experiment are comparable to those obtained in the earlier experiment, the adjusting procedure could be used with greater confidence in subsequent experiments.

It might be useful to modify the adjustment of the variable parameter to make it more difficult for subjects to determine how that adjustment occurs. This would prevent them from employing choice strategies (although this is less likely to be a problem when choice probabilities are not announced). Rather than adjusting an alternative's probability or delay based on the last choice, it could be adjusted using an average of, for example, the last four choices. If the last four choices show no preference for either alternative, no adjustment would be made; if one alternative was chosen three or four times, the variable parameter would be adjusted accordingly.

If a new model successfully describes choice in situations similar to those typically used in behavioral experiments, then one could test its applicability in situations involving long-run choice when parameters are verbally described. The issue of interest here is whether the indifference points obtained are similar to those obtained when probabilities and delays are inferred. It might be observed that the same indifference points are obtained when parameters are identified, but that the indifference points are attained more quickly than when parameters have to be inferred. If the obtained indifference points are different, it may be that people treat declared probability differently than inferred probability.

A final experiment could employ a procedure closer to that of Kahneman and Tversky, presenting subjects with verbally described choices between probabilistic and delayed reinforcers, but in the absence of feedback about the outcomes of choices. As in the previous experiment, the intent would be to determine whether people treat verbally described probabilities in single choice situations in the same way that they treat inferred probabilities. The more specific question to be addressed is whether it is verbal descriptions or the feedback that control patterns of choice. If not, it may be necessary to conclude that no synthesis of behavioral and cognitive models is possible and to accept the necessity for two types of models describing choice between alternatives with probabilistic outcomes.

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Table 1

<u>Group means of final number of risky wheel white sections (standard deviations in parentheses)</u>

	Starting probability	
Trial duration	Low	High
	Ten trials	
30 s	6.0 (2.39)	9.8 (2.25)
90 s	5.5 (2.98)	10.3 (3.11)
	Thirty trials	
30 s	7.5 (2.78)	10.3 (2.71)
90 s	5.1 (1.46)	8.5 (3.67)

Table 2

Group means of proportion of choices made on risky wheel (standard deviations in parentheses)

Trial duration	Starting probability: Low	Starting probability: High
	Ten trials	
30 s	.400 (.120)	.513 (.113)
90 s	.425 (.149)	.488 (.155)
	Thirty trials	
30 s	.423 (.068)	.496 (.045)
90 s	.483 (.025)	.525 (.061)

Table 3

Group means of subjects' mean response times (standard deviation in parentheses).

	Starting probability	
Trial duration	Low	High
Ten trials		
30 s	2.165 (0.797)	3.298 (1.036)
90 s	2.987 (1.048)	3.011 (0.859)
Thirty trials		
30 s	1.990 (0.401)	2.284 (0.906)
90 s	2.528 (0.477)	2.546 (0.485)

Table 4

Ratio of risky and sure-thing rates of return (standard deviation in parentheses)

	Starting probability	
Trial duration	Low	High
Ten trials		
30 s	.661 (.486)	1.523 (.839)
90 s	.795 (.781)	1.523 (.464)
Thirty trials		
30 s	.917 (.265)	1.454 (.336)
90 s	.883 (.364)	1.355 (.491)

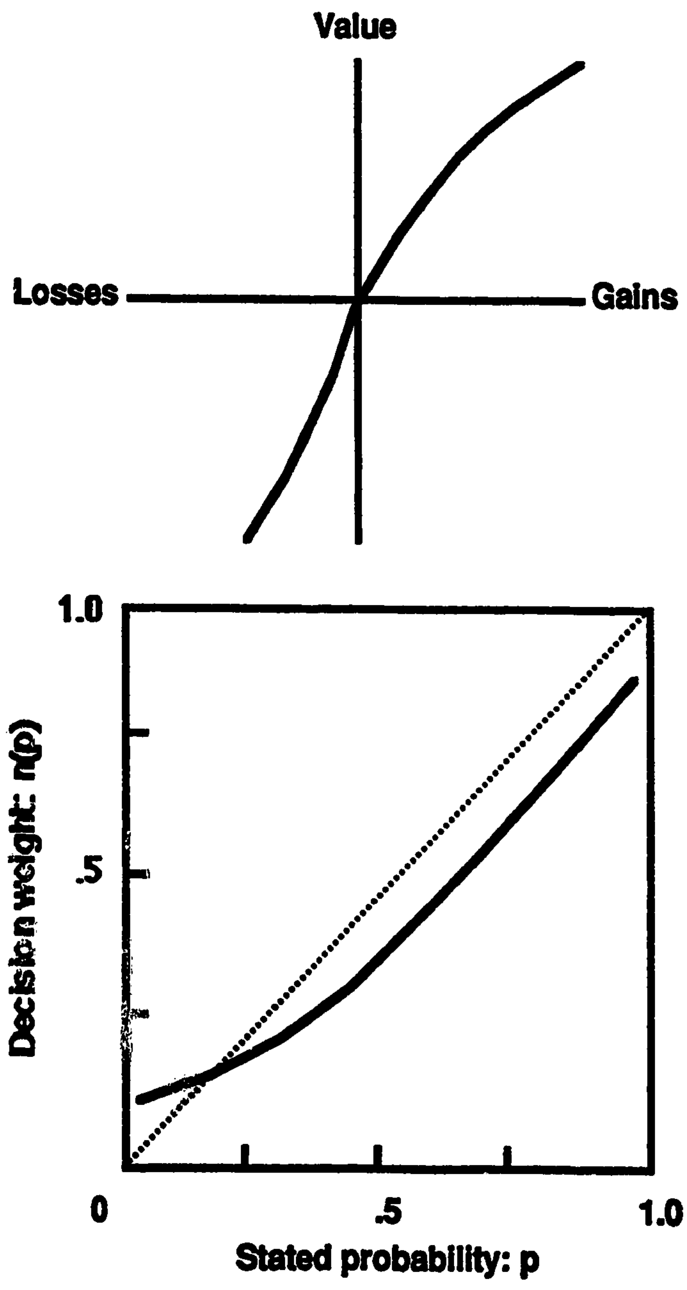

Fig. 1. Hypothetical value function (top) and hypothetical weighting function (bottom). (Adapted from Kahneman and Tversky (1984)).

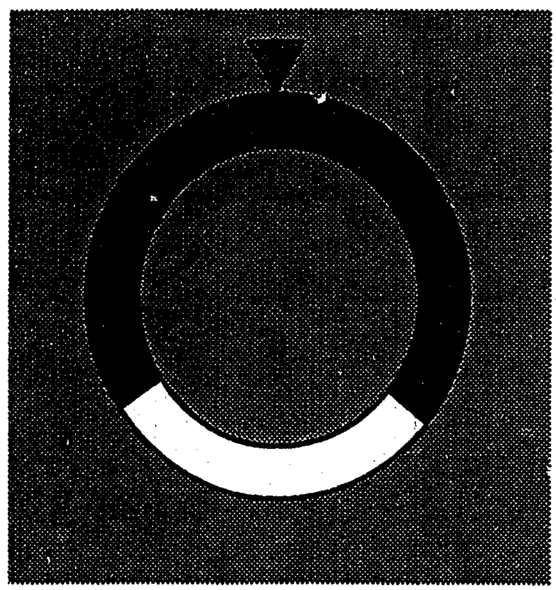

Figure. 2. A risky gambles experiment spinner.

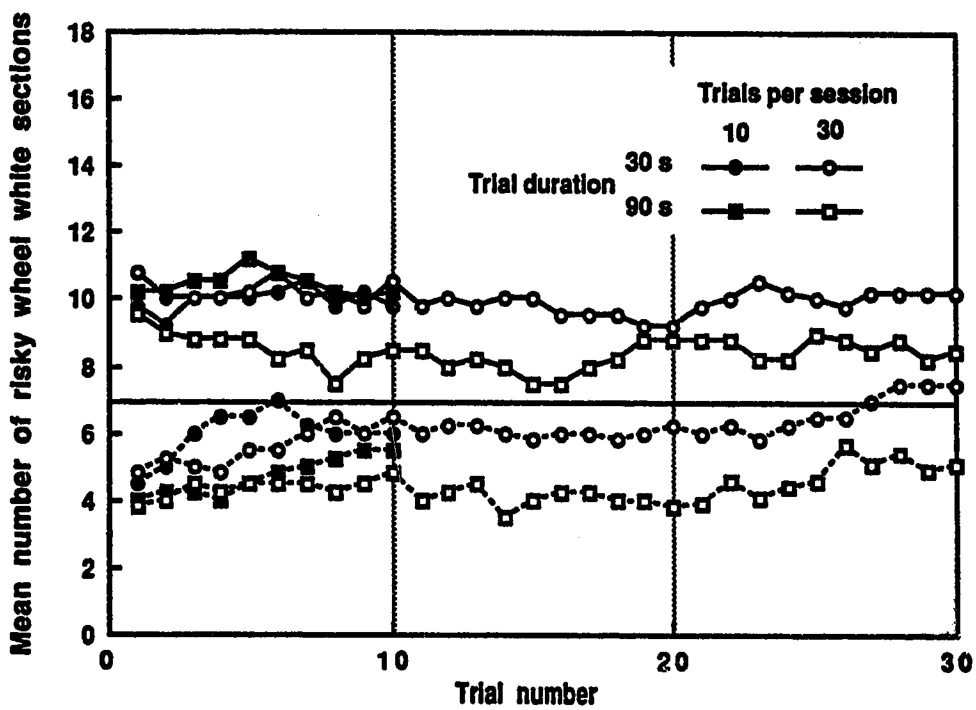

Figure 3. Mean number of risky wheel white sections as a function of trial number for subjects in the 30 trial group. As the number of white sections increases, the probability of winning when choosing the risky wheel increases. Solid line: high starting probability; broken line: low starting probability. The solid line crossing the figure indicates the number of risky wheel white sections that gives the two alternatives roughly the same expected value.

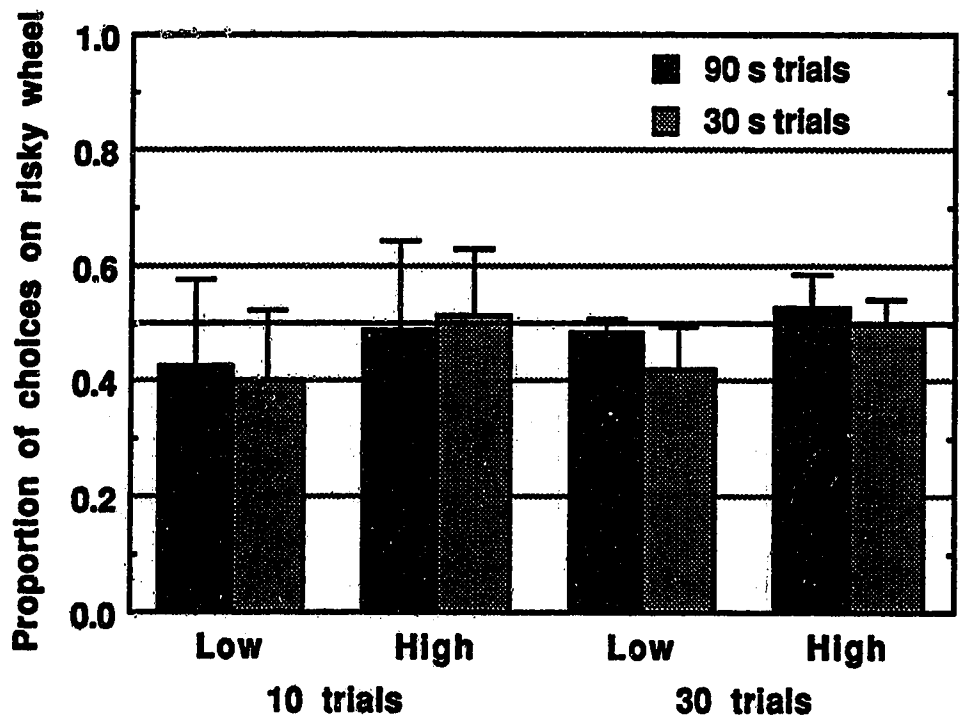

Figure 4. Proportion of choices on risky wheel by group – error bars represent one standard deviation. Solid line indicates point at which wheels are chosen equally often.