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DELAY OR PROBABILITY DISCOUNTING IN A MODEL OF IMPULSIVE BEHAVIOR: EFFECT OF ALCOHOL

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Little is known about the acute effects of drugs of abuse on impulsivity and self-control. In this study, impulsivity was assessed in humans using a computer task that measured delay and probability discounting. Discounting describes how much the value of a reward (or punisher) is decreased when its occurrence is either delayed or uncertain. Twenty-four healthy adult volunteers ingested a moderate dose of ethanol (0.5 or 0.8 g/kg ethanol; $n = 12$ at each dose) or placebo before completing the discounting task. In the task the participants were given a series of choices between a small, immediate, certain amount of money and $10 that was either delayed (0, 2, 30, 180, or 365 days) or probabilistic (i.e., certainty of receipt was 1.0, .9, .75, .5, or .25). The point at which each individual was indifferent between the smaller immediate or certain reward and the $10 delayed or probabilistic reward was identified using an adjusting-amount procedure. The results indicated that (a) delay and probability discounting were well described by a hyperbolic function; (b) delay and probability discounting were positively correlated within subjects; (c) delay and probability discounting were moderately correlated with personality measures of impulsivity; and (d) alcohol had no effect on discounting.

Key words: impulsivity, self-control, delay discounting, probability discounting, alcohol, choice, humans

Impulsive behavior is often defined as insensitivity to the consequences of actions. For example, Oas (1985) defined impulsive behavior as being socially inappropriate or maladaptive, and as being emitted quickly and without forethought. Assuming that an individual has adequate knowledge of the consequences, this definition suggests that individuals who frequently engage in impulsive behavior may fail to evaluate the consequences of their behavior appropriately. This emphasis on consequences is reflected in a commonly used operational definition of impulsivity as being a preference for smaller, more immediate rewards over larger, more delayed rewards (Ainslie, 1975; Herrnstein, 1981; Logue, 1988; Rachlin, 1989; Rachlin & Green, 1972). This operational definition is based on the assumption that the value of a delayed reward is discounted in inverse proportion to its delay. The discounting hypothesis of impulsivity suggests that the degree of discounting due to delay is a measure of an individual's impulsivity. It is proposed that the value of future (delayed) consequences declines more sharply as a function of delay for impulsive than for nonimpulsive individuals; therefore, impulsive individuals tend to choose immediate smaller rewards more frequently than do nonimpulsive individuals.

Correspondingly, the value of a probabilistic reward decreases as its probability decreases. Researchers have suggested that discounting of value produced by decreased probability and discounting produced by delay are fundamentally the same process for two quite separate reasons. First, in the nonlaboratory situation, rewards that are delayed for long periods often become less certain. Therefore, rewards obtained after longer delays may be perceived as being less certain than rewards obtained after shorter delays (Logue, 1988; Mischel & Grusec, 1967; Rotter, 1954). Alternatively, Rachlin, Logue, Gibbon, and Frankel (1986) suggested that a series of probabilistic uncertain rewards is experienced as a series of delayed rewards. For example, if flipping a coin repeatedly and betting on heads each time results in a series of wins and losses,

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the delay between each win may determine the effective value of the reward. Thus, the larger the string of losses between each win, the greater the delay to the next reward. If the same process underlies both delay and probability discounting, then individuals who show sharp discounting of the reward value due to increasing delay should also show sharp discounting due to decreasing probability, and thus exhibit a preference for more certain (higher probability) rewards. This implies that the degree to which individuals discount probabilistic rewards may be another measure of impulsivity.

Recent research with humans (Green, Fry, & Myerson, 1994; Kirby & Marakovic, 1995; Rachlin, Raineri, & Cross, 1991), pigeons (Mazur, 1987), and rats (Bradshaw & Szabadi, 1992; Richards, Mitchell, de Wit, & Seiden, 1997) indicates that delay effectively decreases the value of rewards, and that this discounting of reward value is described by a hyperbolic discount function (Mazur, 1987):

$$\text{value} = A/(1 + kD), \quad (1)$$

where A is the amount of the reward, D is the delay to reward, and k is a free parameter. Larger values of k indicate more marked devaluation of reinforcer value by delay, and thus greater impulsivity. The hyperbolic model predicts that value is discounted more rapidly at shorter delays than at longer delays. In contrast, older economic models (Samuelson, 1937) hypothesized that value discounting is exponential, that is, that reward value is discounted at the same rate regardless of the length of the delay. This is described by

$$\text{value} = Ae^{-kD}, \quad (2)$$

where A is the amount of the reward, D is the delay to reward, and k is a free parameter that indicates the rate of discounting. The value of k has the same interpretation as in Equation 1. It is important to determine if discounting by delay is hyperbolic or exponential because the two models frequently make different predictions. Interestingly, depending upon the delays and the size of the rewards, the hyperbolic model may predict a reversal of preference as the delay to reward changes, whereas the simple exponential model does not (Ainslie, 1975; Rachlin & Green, 1972). Recent research has shown that delay discounting in individual subjects is better described by a hyperbolic than an exponential function (Kirby & Herrnstein, 1995; Mazur, 1987; Myerson & Green, 1995; Rachlin et al., 1991). There are, however, no studies demonstrating that probability discounting is better described by a hyperbolic than an exponential discount function in individual subjects.

As discussed above, Rachlin and colleagues (Rachlin, 1990; Rachlin, Castrogiovanni, & Cross, 1987; Rachlin et al., 1986, 1991) and Mazur (1993) have argued that delay of reward and uncertainty of reward affect behavior in the same way. Thus they hypothesize that discounting by either delay or probability is controlled by the same underlying process. To make this point, Rachlin et al. (1986, 1991) suggested that the subjective value of uncertain rewards is best characterized by ''odds against,'' which is the average number of losses expected before a win. Because each loss adds to the delay to the next win, the number of losses between each win is a better indicator of the subjective experience of the delays between wins than is the strict statement of probability. Using this reasoning, Rachlin et al. (1991) used odds against to extend the hyperbolic and exponential delay discount models (Equations 1 and 2) to the situation in which value is discounted by probability:

$$\text{value} = A/(1 + hO),\ O = (1/p) - 1 \quad (3)$$

and

$$\text{value} = Ae^{-hO},\ O = (1/p) - 1, \quad (4)$$

where p is the probability of reward and O indicates odds against. In this formulation, the value of h indicates how rapidly the value of a reward decreases as the probability of its occurrence decreases. The interpretation of h is directly analogous to the interpretation of k in Equation 1. Just as k in Equations 1 and 2 describes how rapidly the value of a reward is discounted by delay, h in Equations 3 and 4 describes how rapidly the value of a reward is discounted by uncertainty. The implication is that the discounting of both delayed and probabilistic rewards should be greater for impulsive than for nonimpulsive participants. Using this model, Rachlin et al. (1991) found that the hyperbolic model better described discounting of reward value when probability was varied in human sub-

jects. However, their data were based on fitting the median discount values for a relatively large group of subjects ($N = 40$). From these data, it is not clear whether the equivalence of delay and probability holds at the level of an individual participant. For example, do individuals who display greater delay discounting also show greater probability discounting?

In the present study, we tested the hypothesis that discounting of value by delay and by probability represents the same process by determining discount functions for both delay and probability within the same subjects. This hypothesis predicts that individuals who display greater delay discounting should also show greater probability discounting. In addition, we fit both hyperbolic and exponential discount equations to the obtained discounting data in order to determine which function (hyperbolic or exponential) better fit the data. Then, in order to examine the construct validity of the discounting model of impulsive behavior, subjects' performances on the discounting procedure were correlated with their scores on standardized personality measures of impulsivity.

Discount functions for delay and probability were calculated for participants who were required to choose between immediate certain amounts of money and either delayed or uncertain larger amounts of money. Across trials the amount of the immediate (or certain) option was adjusted until the participant was indifferent between the two choices. This indifference point indicated for that individual the effective value of the delayed or uncertain large reward relative to an immediate and certain amount of money. Each participant was tested under both delay and probability choice conditions, which enabled us to determine the relation between the delay and probability discounting functions within subjects.

The present study was also designed to assess the effects of alcohol on the discounting model of impulsivity. Similarities in the effects of a drug on discounting by delay and probability would support the idea that delay and probability discounting are related. Several lines of evidence suggest that alcohol use is associated with greater impulsivity. On questionnaire measures of impulsivity, alcoholics, as well as their offspring, are more impulsive than the normal population (Graham, 1980). At the neurochemical level, both Type II alcoholics and individuals who engage in impulsive violence and impulsive fire setting have low rates of turnover of the neurotransmitter serotonin in the brain, as measured by serotonin metabolites in cerebrospinal fluid (Linnoila, Virkkunen, Roy, & Potter, 1990; Virkkunen & Linnoila, 1990). Type II alcoholics are individuals who become addicted to alcohol while young and who have a high probability of engaging in violent behavior when intoxicated. In the case of Type II alcoholics, these data do not indicate direction of causality, that is, whether impulsivity in these individuals is greater because of their use of alcohol or whether their alcohol use is excessive because they are relatively impulsive. Some data indicate that alcohol causes impulsive behavior. Retrospective reports by chronic alcohol users frequently include reports of increased impulsive violence (Fendrich, Mackesy-Amiti, Goldstein, Spunt, & Brownstein, 1995; Welte & Abel, 1989) and impulsive sexual behavior (Ericksen & Trocki, 1992; Hingson, Strunin, & Berlin, 1990; McCusker, Koblin, Lewis, & Sullivan, 1990). Chronic alcohol abuse may also cause cognitive deficits characterized by a lack of impulse control (Duffy, 1995). Thus, in the present study, ingesting alcohol was expected to increase impulsivity, as measured by the discounting functions for delayed and uncertain rewards.

To summarize, this study had five main goals: (a) to further develop a laboratory model to measure impulsive behavior in humans using delay and probability discounting, (b) to compare how well hyperbolic and exponential discount models characterize delay and probability discounting, (c) to determine the relationship between delay and probability discounting within subjects, (d) to assess the relationship of delay and probability discounting to a pencil-and-paper test of impulsive personality, and (e) to assess the effects of ethanol on impulsivity using the two procedures.

METHOD

Participants

Twenty-four healthy male and female volunteers (16 males and 8 females), aged 21 to

35 years, were recruited from the university and surrounding community through newspaper advertisements and posters. They were told that the experiment was designed to investigate the effects of drugs on mood and behavior. During initial screening, candidates provided a detailed medical and recreational drug history using standardized questionnaires (e.g., health questionnaire: SCL-90, Derogatis, 1983), underwent a semistructured psychiatric interview, and received a physical examination. Candidates were excluded from the study if they had a significant medical problem, a past or current alcohol or drug problem, or consumed less than one alcoholic drink per week. The local institutional review board approved the experimental protocol.

Materials

Participants were tested in a comfortable room, furnished with upholstered couches and chairs; lamps provided incandescent lighting. The room was equipped with a television, radio, VCR, and a computer (Macintosh SE®) for administering the choice procedure. Breath ethanol levels (BAL) were measured using an Intoximeter Breathalyzer. The ethanol beverage was prepared by stirring a tonic and lime-flavored mix into either 10% v/v (0.5 g/kg dose condition) or 16% v/v (0.8 g/kg dose condition) ethanol. The placebo beverage was the tonic and lime mix in 1% v/v alcohol; the small amount of alcohol was intended to reduce the discriminability between placebo and alcohol beverage. The beverages were presented in a volume of 450 ml per 70 kg of body weight.

Procedure

Each participant was required to come to the laboratory on four separate occasions. The first occasion was an orientation session, the second and third occasions were experimental (ethanol or placebo) sessions, and the fourth occasion was a debriefing interview.

Orientation session. The orientation session took place on a separate day after the initial screening procedure described above. During the orientation session, the participants read and signed a consent form, which explained the nature and the procedure of the study. The two primary sections of the form are given below.

I. NATURE AND DURATION OF PROCEDURE:

The purpose of this study is to investigate how drugs influence your preferences in a choice task in which you receive varying amounts of money at various time delays, or with various odds. You will come to the laboratory for 3 experimental sessions conducted 3 times a week. Sessions will be held from 6:00 to 9:20 p.m. During the experimental sessions you will complete some questionnaires, perform a preference task, ingest capsules and beverages. Depending on your choices during the preference task you may earn varying amounts of money, which you will receive at the end of the session or after some longer delay.

The capsule and beverage you take may contain a low to moderate dose of any of the following drugs: stimulant/anorectic, sedative/tranquilizer, alcohol or placebo (inactive substance). The drugs used in the study are commonly prescribed or over-the-counter nonexperimental drugs. The doses are clinically safe and are not likely to cause any discomfort. Possible drug effects are listed in the section below.

You will take no drugs other than that administered by the experimenter for 24 hours prior to, as well as for 12 hours following, all sessions. This prohibition includes alcohol, marijuana, aspirin, and any other drugs which are not necessary medications (except caffeine and nicotine). Urine samples will be obtained on a random basis to verify that you have not used drugs. Positive urine tests will cause dismissal from the study. If you must take a drug for medication, you will inform the experimenter before the experimental session. You agree not to drive or operate complex machinery for 12 hours after the session. You will be transported home after the session. The session will end at 9:20 p.m., unless the experimenter determines you are impaired. In this unlikely event, you will remain in the laboratory until 10 p.m.

If female, you agree that you are not currently pregnant or planning to become pregnant. Additionally, you must take a pregnancy test before participating in the study. Should you become pregnant or suspect a pregnancy at any time during the study, you will notify the experimenter immediately.

You must obtain the experimenter's permission if you wish to participate in another research study while you are enrolled in this one. You understand that you are free to withdraw from the study at any time.

II. POTENTIAL RISKS AND/OR BENEFITS

Side effects of the drugs to be used in this study may include: constipation, drowsiness, lethargy, dizziness or faintness due to lowering of blood pressure, changes in heart rate or blood pressure, a feeling of fluttering of the heart, restlessness, tenseness, irritability, headache, nausea, paleness or flushing, sweating, and dry mouth. Other side effects are also possible. The experimenter should be informed of any symptom or feeling which you associate with the drug taken for the experiment. In the unlikely event that you require medical attention, the emergency room physician will be notified. The psychiatrist who is associated with our research group will also be notified.

You understand that this study is not meant to benefit you as an individual participant, beyond the monetary payment. The results of the study will contribute to our knowledge of factors influencing drug use.

After completing all sessions you will attend a debriefing interview. Here you will complete four personality questionnaires which should take approximately 40 minutes of your time. Also during the debriefing session, the purpose of the study will be explained to you and any questions you have concerning the study will be answered. You will then be paid $75 for participating in the study, in addition to any money earned from the preference task. If you withdraw prior to completing the study, you may receive partial payment depending on the reason for withdrawal. If you miss sessions or are late for sessions, you may be dropped from the study without any financial compensation.

The participants were told orally not to eat before the session. After the participants signed the consent form, they were given a practice session on the computerized choice procedure described below. The practice session included selection of a reinforcer (although the participants did not receive it).

Experimental sessions. Following the orientation session, each participant participated in two experimental sessions, which were conducted from 6:00 to 9:20 p.m., and were 2 to 5 days apart. Participants were tested individually. Upon arrival in the laboratory at 6:00 p.m., each subject's (BAL) was measured to verify that he or she was ethanol free. At 6:20 p.m., participants completed the predrug choice procedure, self-report questionnaires, and a psychomotor task described below. At 6:40 p.m., participants ingested a capsule and consumed a beverage within 10 min. The capsule was always a placebo and was included to enhance the blind conditions of the study. The beverage was one of two doses of ethanol or placebo. The order in which participants received the ethanol and placebo beverages was counterbalanced. Twelve participants (7 males and 5 females) received a low dose of ethanol (0.5 g/kg; equivalent to about three standard alcoholic drinks), and the other 12 participants (9 males and 3 females) received a moderate dose of ethanol (0.8 g/kg; about four to five standard drinks). At 7:10 p.m., 20 min after finishing the beverage, BALs were measured again, and participants completed the postdrug choice procedure, self-report questionnaires, and the psychomotor test. After completing these procedures, participants relaxed in the laboratory for the remainder of the session. At 9:20 p.m., they were paid any money earned in the choice procedures and were transported to their homes.

Choice procedure. A computerized choice procedure was used to assess discounting of delayed and uncertain reinforcers. The procedure was verbally explained to the participants as follows:

> You will have the opportunity to choose between different amounts of money available after different delays or with different chances. The test consists of about 110 questions, such as the following: (a) Would you rather have $10 for sure in 30 days or $2 for sure at the end of the session, or (b) would you rather have $5 for sure at the end of the session or $10 with a 25% chance? At the end of the session, one of the choices you made will be selected at random and you will receive whatever you chose in response to that question. If on that trial you selected an immediate amount of money, you will receive the money in cash at the end of the session. If you selected delayed money, the money will be placed in an envelope with your name on it, and it will be available to you when the time has elapsed. If you selected a probabilistic amount, you will select a token from a bag containing two colors of tokens in the proportion that reflects the probability. For example, if the trial you selected was $10 with a 25% chance, you will select one token from a bag containing 1 green token representing "get $10" and 3 yellow tokens representing "get $0." You will receive the amount of money indicated by the color of the token immediately in cash.

After explaining the procedure, the experimenter told the subject to begin answering the questions presented on the computer screen. The experimenter then left the room for 15 min. The program was designed to terminate automatically and save the experimental data after predetermined indifference-point criteria had been achieved (described below). If the computer program had not terminated by the time the experimenter returned, the experimenter waited in the room for the program to terminate.

At the end of each experimental session (9:20 p.m.) the experimenter randomly selected one of all the trials completed during that session for a choice to be reinforced. This selection took place in view of the participant to demonstrate that the selection was random. If the earned money was immediate, he or she was given the money immediately. If the earned money was delayed, the participant was shown an envelope labeled with his or her name and containing the money to assure him or her that the money would be available after the specified delay interval. The envelope was then mailed at the completion of the specified delay.

The procedure was intended to be analogous to the adjusting-amount procedure we previously used to study discounting of reward value by delay in rats (Richards et al., 1997). In the present study, the amount of immediate certain money was adjusted across successive questions (trials) presented to the participants on the computer screen until an amount was reached that was determined by the participant's choices as equivalent to a delayed (delay trials) or uncertain (probability trials) $10 reward. The amount of immediate certain money the participant judged to be equivalent to the $10 reward was taken to indicate the subjective value of the delayed or uncertain rewards. These points of subjective equality were called indifference points. Delay and probability trials were intermixed; each session consisted of approximately 110 trials.

Within each session, indifference points for five different delays were determined: 0, 2, 30, 180, and 365 days. On delay trials, participants were asked to choose between an amount of money available immediately and $10 available after some delay. The immediate amount of money was varied systematically across trials for each delay interval by use of a random adjusting-amount procedure (described in detail below). For example, on delay trials, participants might be presented with the question, ''Would you rather have (a) $6 now or (b) $10 in 30 days?'' and were asked to indicate their choice on the computer keyboard. Indifference points for five different probabilities were also determined: 1.0, .9, .75, .5, and .25. On probability trials, participants chose between a variable amount of money delivered for sure ($p = 1.0$) and $10 to be delivered on a probabilistic basis. The amounts of for-sure money were varied systematically across trials at each probability level, using the random adjusting-amount procedure (see below). For example, on probability trials, the participants might be presented with the question, ''Would you rather have (a) $4 for sure or (b) $10 with a 50% chance?''

A random adjusting-amount procedure was programmed to use the answers to previous questions to narrow the range of values from which the value for the next question was selected. This reduced the number of questions needed to estimate the indifference points for the delay and probability discount functions for an individual. The adjusting nature of the task was masked by mixing delay and probability questions and by not using a predictable algorithm for determining the adjusted value for the subsequent questions. The procedure allowed discount functions for both delay and probability to be determined in less than 15 min. The median number of questions (trials) needed to determine the 10 indifference points (five for delay and five for probability) in this study was 103. The maximum number of trials was 148, and the minimum number was 74. No participant reported or indicated in any way that he or she detected the adjusting nature of the task.

In this description of the random adjusting-amount procedure, the delayed $10 and the probabilistic $10 will be referred to as the standards. The values of 10 different standards were estimated in this study, five delays and five probabilities. The adjusting amounts of immediate money on the delay trials and for-sure money on the probability trials will be referred to as the variable amounts. The variable amounts correspond to the randomly selected amounts between top and bottom

limits. These limits changed according to the subjects' choices as the session progressed. In order to minimize the effects of subject error (e.g., due to inattention), there were two top limits (the maximum top limit and the minimum top limit) and two bottom limits (the maximum bottom limit and the minimum bottom limit). The maximum top limit was greater than the minimum top limit, and the maximum bottom limit was always less than the minimum bottom limit. These four limits could vary independently.

On each trial, the participant made a choice between a standard and a variable amount. On the first trial for each standard, the maximum and minimum top limits were set to $10, and the maximum and minimum bottom limits were set to $0. On all trials, the variable amount was randomly selected from the range of values between the maximum top limit and the maximum bottom limit in $0.50 increments (i.e., on the first trial the variable amount could be anywhere between $0 and $10 in $0.50 steps). The range of values from which the variable amount was chosen was adjusted systematically on succeeding trials. That is, if the participant chose the standard, the top and the bottom limits on the trial following it increased according to three rules: (a) If the variable amount was greater than the minimum bottom limit, the minimum bottom limit was set equal to the variable amount and the maximum bottom limit was set equal to the previous minimum bottom limit. (b) If the variable amount was less than the minimum bottom limit, the maximum bottom limit was set equal to the variable amount and the minimum bottom limit was left unchanged. (c) If the variable amount was greater than the minimum top limit, the minimum top limit was set equal to the current variable amount and the maximum top limit was set equal to $10. This procedure for increasing the top and bottom limits caused the variable amount to increase on the following trial. However, if the participant chose the variable amount, the top and the bottom limits on the next trial decreased according to three rules: (a) If the variable amount was less than the minimum top limit, the minimum top limit was set equal to the variable amount and the maximum top limit was set equal to the previous minimum top limit. (b) If the variable amount was greater than the minimum top limit, the maximum top limit was set equal to the variable amount and the minimum top limit was left unchanged. (c) If the variable amount was less than the minimum bottom limit, the minimum bottom limit was set equal to the variable amount and the maximum bottom limit was set equal to $0. This procedure for decreasing the top and bottom limits caused the variable amount to decrease on the following trial. When the difference between the maximum bottom limit and the maximum top limit reached $0.50, the corresponding variable amount was taken as the estimate of the indifference point. After an indifference point had been determined for a particular standard, questions about that standard were no longer presented. However, in order to mask the adjusting nature of the procedure, distracter trials were added after 70 trials had been completed. After 70 trials, 50% of the presented trials were distracter questions, which consisted of questions about any of the 10 standards; the variable amount varied randomly between $0 and $10.

Subjective measures and psychomotor measure. Participants completed two questionnaires to assess the drug effects. A 49-item version of the ARCI consists of 49 true-false statements, which are clustered into five scales to measure typical drug effects. The Pentobarbital-Chlorpromazine-Alcohol Group (PCAG) scale measures sedative effects, the Amphetamine (A) and Benzedrine Group (BG) scales measure stimulant-like effects, the Morphine-Benzedrine Group (MBG) scale reflects drug-induced euphoria, and the Lysergic Acid (LSD) scale reflects dysphoria and somatic effects. The DEQ consists of four visual analogue scales associated with questions regarding the degree to which participants "feel" and "like" the effects they experience, whether they are "high," and whether they want "more," respectively. Participants mark their responses along 100-mm lines labeled *not at all* (0) to *very much* (100). Subjects' psychomotor performance was tested using the Digit Symbol Substitution Test (DSST; Wechsler, 1958). The DSST is a standard measure of cognitive and psychomotor performance. It requires participants to substitute a series of symbols for numbers within 60 s. The subjective and psychomotor tests were administered in pencil-and-paper form.

Debriefing interview. A debriefing interview was conducted after participants completed the experimental sessions. During the debriefing session, participants filled out the following personality tests: the Eysenck Personality Inventory (EPI; Eysenck & Eysenck, 1968), the Impulsiveness-Venturesomeness-Empathy questionnaire (IVE; Eysenck & Eysenck, 1978), the Sensation Seeking Scale (SSS; Zuckerman, 1971), and a fourth personality questionnaire that was dropped from the data analysis due to concerns about its reliability.

Data Analysis

The dependent variable of greatest interest in this study was the indifference point (obtained using the random adjusting-amount procedure). Indifference points were used to estimate delay and probability discount functions for each participant. Equations 1 and 2 were fit to the five delay indifference points using a nonlinear curve-fitting program (Origin 4.1, 1995). This curve-fitting program determined the best fitting values for k and the coefficient of determination for delay discounting. Similarly, Equations 3 and 4 were fit to the five probability indifference points to determine the values of h and coefficient of determination for probability discounting. In plotting the discount functions for probability, we have chosen to plot the data with ''odds against winning'' (rather than probability) on the x axis in order to make clear the hyperbolic nature of the discount function. Odds against winning for a given probability value is provided by computing O in Equation 3; thus, the five probability values used in this study (1.0, .9, .75, .5, and .25) were converted to 0, 0.11, 0.33, 1.0, and 3.

As previously described, both male (n = 16) and female (n = 8) volunteers participated in this study. Because our analysis of the data indicated no consistent gender differences and because the study was not designed to detect gender effects, we have combined the data in our analysis. However, the gender of individual subjects is indicated in Appendix A.

In an analysis of the group data, median values for the delay and probability indifference points were used because, as previously described by Myerson and Green (1995) and Rachlin et al. (1991), the indifference points were skewed because of the limits imposed on the obtained indifference points by the maximum ($10) and minimum ($0) values (i.e., no matter how short the delay, $10 would never be worth more than $10, and no matter how long the delay $10 would never be worth less than $0).

In order to assess the effects of alcohol on discounting pre- and postplacebo and pre- and postethanol, k and h values for each dose were compared using within-subject t tests. In addition, the obtained indifference points for delay and probability discounting were statistically analyzed using a two-way within-subject analysis of variance with pre- and postdrug as one factor and delay (or probability) as the second factor.

Wilcoxon matched-pairs signed-rank t tests were also used to assess the effects of ethanol consumption on BAL, the DSST, the DEQ visual analogue scales, and the ARCI scales. In all cases, pre- and postplacebo and pre- and postethanol values for the two doses were compared using within-subject t tests. For all statistical tests, the probability level required for significance was $p \leq .05$.

RESULTS

As expected, the subjects' indifference points declined as the delay for delivering the $10 increased and as the probability for receiving the $10 decreased. Figures 1 and 2 show the indifference points for each of the 24 subjects. The delay and probability indifference points presented in Figures 1 and 2 are the average of the indifference points obtained during the preplacebo and preethanol tests for each subject. These indifference points were then fit with the hyperbolic and exponential discount functions to produce k and h values, which are shown in Table 1. The pre- and postplacebo and pre- and postethanol k and h values for each of the 24 participants are shown in Appendix A. The individual-subject pre- and postplacebo and pre- and postethanol discount points for each of the 24 participants are listed in Appendix B for delay and Appendix C for probability. Appendixes A, B, and C show that there was a good degree of test–retest reliability with repeated testing with the discounting procedure.

Individual participants performed similarly on the delay and probability components (Figures 1 and 2). However, there were sub-

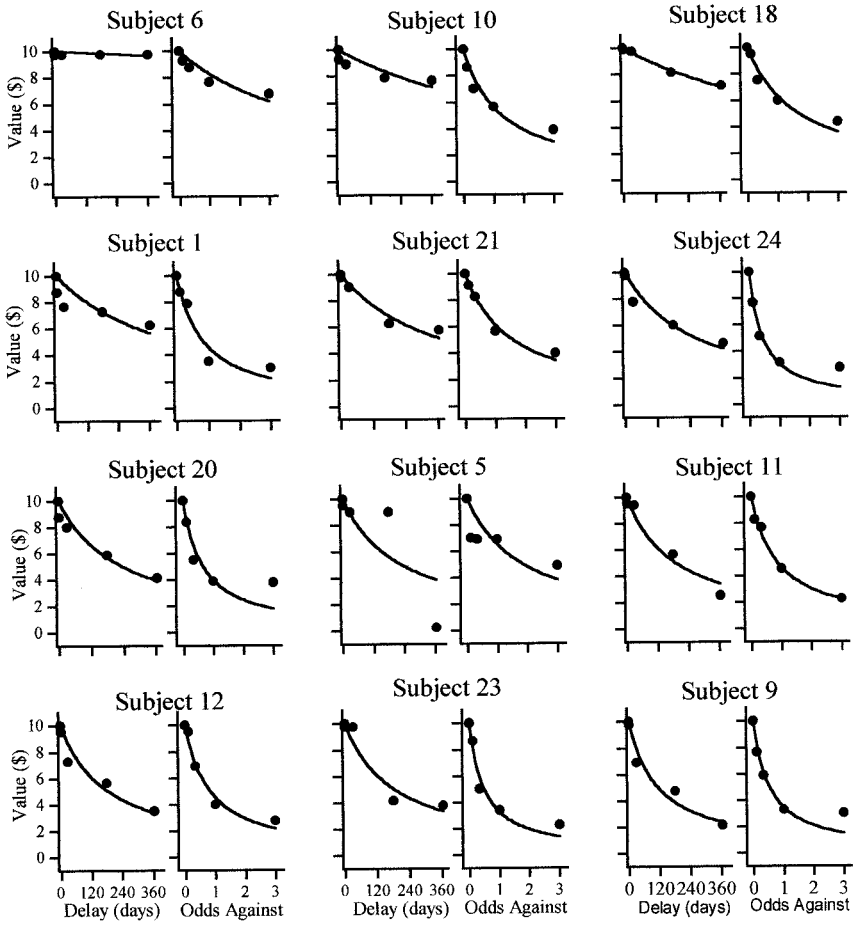

Fig. 1. Individual discounting curves for the 12 least impulsive participants. For each participant, the delay condition data are displayed on the left and the probability condition data are displayed on the right. The solid line represents the best fit of the relevant hyperbolic function (Equation 1 or Equation 3). Panels are arranged according to the values of k, which indexes the steepness of the hyperbolic function in the delay condition. Beginning at the top left, the 1st participant (Participant 6) had the smallest k in the delay condition, and at the bottom right, the last participant (Participant 9) had the median k in the delay condition. The values of k and h for each subject are given in Table 1. To facilitate comparisons between the delay and probability condition data, the five probability values (1.0, .9, .75, .5, and .25) are expressed as odds against winning (0, 0.11, 0.33, 1.0, and 3).

stantial individual differences in the slopes of the discounting curves. Figures 1 and 2 show the 24 subjects' performances, ordered (from top to bottom of the figure) in terms of the steepness of their delay discount functions. These figures indicate that at the individual-participant level, the rate of delay and probability discounting was positively associated. For example, Participants 6, 10, and 18 showed relatively little discounting in either delay or probability conditions, whereas Participants 14, 15, and 8 displayed the steepest discounting in both conditions. The scatter plot in Figure 3 shows the positive correlation between delay and probability discounting for the k and h values for the data shown in Figures 1 and 2 more directly. The correlation between delay and probability discounting was statistically significant, Pearson's $r = 0.749$, $p < .0001$.

When both hyperbolic and exponential functions were fitted to the median indifference points (Figure 4), the hyperbolic model showed a slightly better fit for the delay discounting and a clearly better fit for the probability discounting. Figure 4 presents the me-

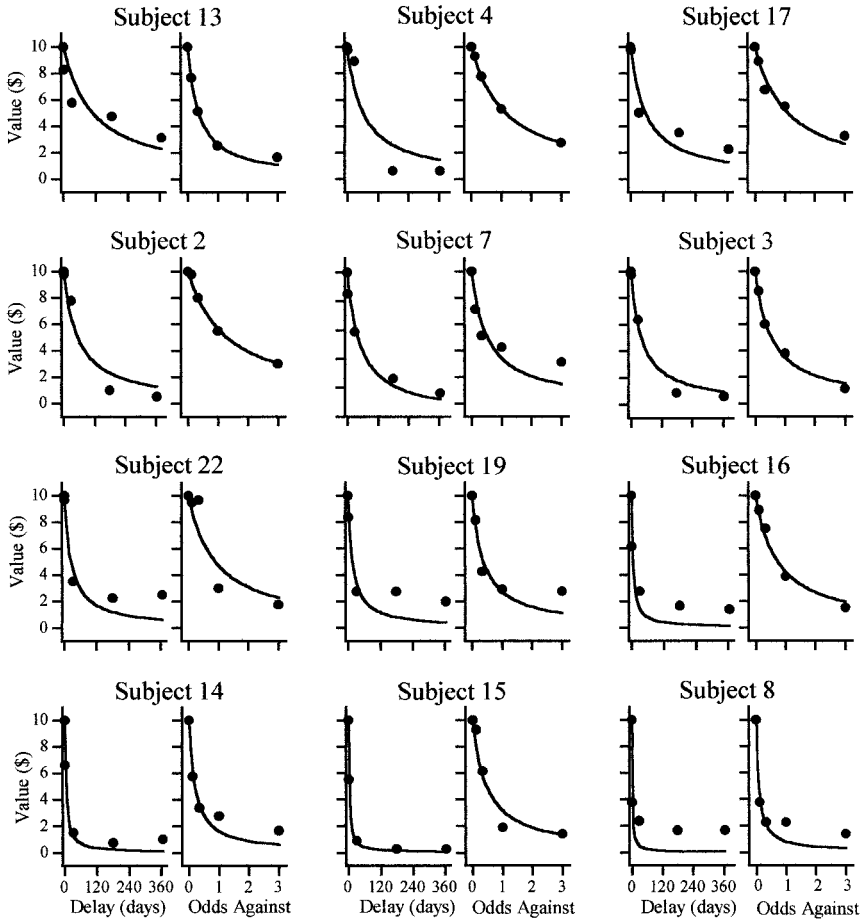

Fig. 2. Individual discounting curves for the 12 most impulsive participants. Beginning at the top left, the 1st participant (Participant 13) had the median k in the delay condition, and the last participant (Participant 8) had the greatest k in the delay condition. Other details as for Figure 1.

dians of the indifference points and the best fits for the hyperbolic and exponential models. Inspection of the top panel shows that, compared to the hyperbolic model, the exponential model overestimated the indifference points at short delays and slightly underestimated them at longer delays. The hyperbolic model explained 98.5% variance for the delay data, whereas the exponential model explained 95.2%. Similarly, in the probability trials, the exponential model overvalued high-probability (or low odds-against-winning) rewards, and undervalued low-probability (or high odds- against- winning) rewards (bottom panel of Figure 4). The hyperbolic model explained a higher percentage of variance (r^2 = 98%) for the probability data than the exponential model (r^2 = 87%).

The superiority of the hyperbolic model in accounting for variance in the data was also evident in the individual subjects' indifference points (Table 1). In order to help determine whether the apparent differences in goodness of fit between the hyperbolic and exponential model shown in Figure 4 were meaningful, a statistical analysis was performed on the r^2 values obtained from fits to the individual-subject data. Table 1 shows the k values for the delay trials and the h values for the probability trials and gives the percentage (r^2) of variance explained by hyperbolic and exponential discounting models for individual subjects. On the delay component, the median r^2 for fits to individual subjects' data was 91.5% for the hyperbolic model versus 87% for the exponential models. When

Table 1

Summary of the k and h values and the proportions of variance for the fits to the hyperbolic and exponential discounting models for the 24 participants. The k and h values for each participant were obtained by fitting hyperbolic and exponential discounting functions to the average indifference points of four choice test sessions: pre- and postplacebo and pre- and postethanol.

	Delay condition				Probability condition			
	Hyperbola		Exponential		Hyperbola		Exponential	
Participant	k	r^2	k	r^2	h	r^2	h	r^2
1	0.002	.4	0.002	.33	1.181	.94	0.745	.86
2	0.019	.95	0.011	.99	0.767	.99	0.491	.97
3	0.025	.98	0.014	.99	1.865	.99	1.117	.97
4	0.016	.91	0.010	.97	0.881	.99	0.550	.96
5	0.004	.63	0.003	.71	0.540	.27	0.320	.05
6	0.000	—[a]	0.000	—[a]	0.208	.79	0.160	.70
7	0.020	.97	0.009	.87	1.919	.81	1.069	.50
8	0.700	.82	0.490	.78	11.38	.92	6.984	.81
9	0.009	.96	0.005	.92	1.904	.92	1.199	.73
10	0.001	.57	0.001	.52	0.786	.91	0.454	.76
11	0.005	.97	0.004	.99	1.166	.99	0.710	.94
12	0.005	.92	0.003	.87	1.219	.97	0.754	.90
13	0.009	.72	0.004	.57	2.769	.99	1.72	.93
14	0.230	.98	0.200	.95	5.155	.94	3.279	.78
15	0.402	.99	0.299	.99	2.178	.95	1.451	.96
16	0.196	.89	0.241	.78	1.367	.99	0.862	.99
17	0.019	.91	0.007	.76	0.913	.95	0.530	.84
18	0.001	.99	0.001	.99	0.591	.94	0.367	.84
19	0.063	.87	0.045	.78	2.659	.91	1.786	.76
20	0.004	.90	0.003	.86	1.534	.83	0.897	.56
21	0.003	.95	0.002	.90	0.637	.98	0.402	.90
22	0.041	.91	0.034	.81	1.120	.86	0.773	.89
23	0.006	.94	0.004	.93	2.096	.96	1.325	.85
24	0.004	.92	0.003	.87	2.304	.93	1.471	.75
Median	0.009	.915	0.004	.87	1.293	.94	0.817	.845

[a] The nonlinear curve-fitting program was unable to provide delay r^2 values for Participant 6.

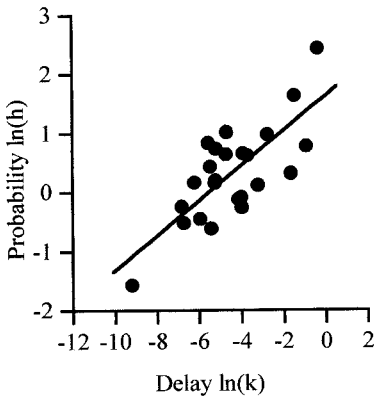

Fig. 3. Scatter plot of k in the delay condition versus h in the probability condition after natural log transformation, that is, $\ln(k)$ versus $\ln(h)$. Each data point represents the value of h for probability as a function of the value of k for delay for an individual participant. The k and h values are the hyperbolic model data presented in Table 1.

the r^2 values for individual subjects for the hyperbolic fits were compared with the r^2 for the exponential fits, the hyperbolic fits were found to be significantly better, according to Wilcoxon matched-pairs signed-ranks test, $t = -2.83$, $p < .005$. Similarly, on the probability components, the median r^2 for fits to individual subjects' data was 94% for the hyperbolic model versus 84.5% for the exponential model. The Wilcoxon matched-pairs signed-ranks test indicated the hyperbolic discounting model to be significantly better than the exponential discounting model, $t = -4.16$, $p < .0001$. Note that the medians of the individual-subject r^2 values shown in Table 1 for delay and probability differ from the r^2 values calculated using the median indifference points of the group data shown in Figure 4. However, examination of the individual-subject plots in Figures 1 and 2 shows that Figure

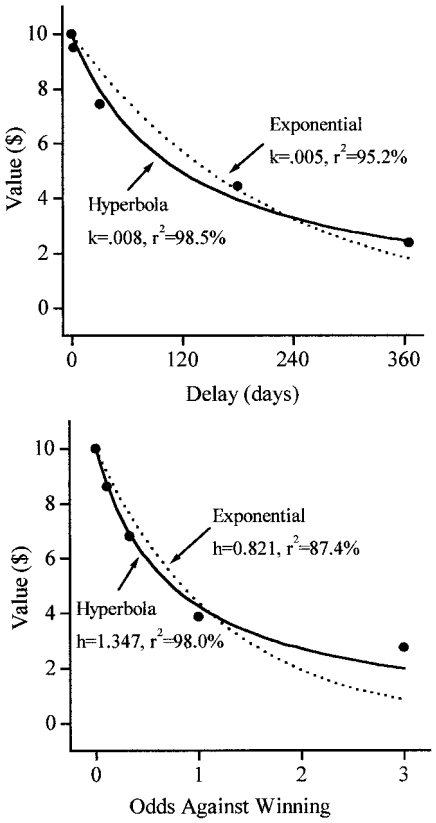

Fig. 4. Discounting curves for the group data. The data points represent the median amount of immediate money estimated to be equivalent to the delayed $10 (top panel) and to the probabilistic $10 (bottom panel). The solid curve represents the best fit of a hyperbolic discounting function (Equations 1 and 3), and the dotted curve represents the best fit of an exponential discounting function (Equations 2 and 4).

4 provides a good characterization of the systematic deviations of the individual subjects from the hyperbolic and exponential discount models. Thus, the group data from Figure 4 and the individual data from Table 1 indicate that the hyperbolic model appropriately described both delay discounting and probability discounting.

Ethanol had no effect on the discounting of either delayed or probabilistic rewards. *t* tests on the pre- and postethanol *k* and *h* values for both doses were not significant (Table 2). In addition, the two-way analysis of variance on the indifference points with drug as one factor and delay (or probability) as the second factor failed to produce a significant effect of drug or a significant interaction of drug with delay (or probability). The results of the *F* tests are shown in Appendix D. Although there was a significant effect of placebo in the delay component in the high-dose group, this was probably a chance finding resulting from the number of *F* tests performed (i.e., Type I error). The lack of effect of alcohol on discounting of delayed and probabilistic rewards is also indicated by comparison of the pre- and postethanol *k* and *h* values for individual subjects, shown in Appendix A. The pre- and postethanol delay and probability indifference points for the individual subjects are presented in Appendixes B and C.

Although alcohol had no effect on discounting of delayed and probabilistic rewards, Table 2 shows that BALs were increased in a dose-dependent fashion (0.044 mg/dl and 0.067 mg/dl for the 0.5 g/kg and 0.8 g/kg doses, respectively). Participants reported significant subjective effects at both doses of alcohol. Relative to predrink baseline, the low dose of alcohol significantly increased scores on the PCAG scale (i.e., sedation) of the ARCI, on "feel drug," "feel high," "want more" scales of the DEQ, and impaired psychomotor performance on the DSST. The moderate dose significantly increased scores on MBG scale (i.e., euphoria) of the ARCI and on all four scales on the DEQ ("feel drug," "feel high," "like drug," "want more"), relative to the predrink scores. The BALs, performance on the DSST task, and the ratings on the subjective effect scales are listed for the individual subjects in Appendixes E and F.

Pearson product-moment correlation coefficients were calculated between *k* and *h* (for the hyperbolic fit) values and impulsivity-related scores on different personality tests. The correlations between *k* (for delay) and impulsivity scores on the IVE (Table 3) and between *k* and the impulsivity and extroversion scale scores on the EPI were not large enough to be significant for an alpha level of .05, nor were the corresponding correlations involving *h* (for probability). Those correlations involving the impulsivity and extroversion scale scores on the EPI, however, were large enough for signficance with a less conservative alpha of .1. Also, both *k* and *h* were significantly correlated with the disinhibition scale score on the SSS ($p < .05$). The individ-

Table 2

Effects of ethanol (0.5 g/kg and 0.8 g/kg) on dependent measures taken after the choice task was completed. *k* and *h* values are median change from the predrink (placebo or alcohol) baseline. Other values are mean (*SEM*) change scores from the predrink (placebo or alcohol) baseline. Change scores were calculated by subtracting predrink scores from postdrink scores for each participant.

Measure	0.5 g/kg		0.8 g/kg	
	Placebo	Alcohol	Placebo	Alcohol
Delay (*k* median)	0.000	0.000	0.003	0.000
Probability (*h* median)	0.001	−0.059	−0.014	−0.059
Breath alcohol (mg/dl)	0.001	0.045**	0.000	0.067**
	(0.000)	(0.007)	(0.000)	(0.006)
DSST	−0.08	−4.83**	−0.42	−3.58
	(0.94)	(1.35)	(0.82)	(1.69)
DEQ				
Feel drug	14.75	66.00**	20.08	73.92**
	(5.27)	(3.80)	(5.39)	(6.55)
Like drug	−1.58	11.67	8.25	28.42**
	(3.65)	(5.53)	(5.21)	(5.84)
Feel high	9.17	48.83**	11.67	70.42**
	(3.88)	(8.01)	(4.49)	(6.02)
Want more	10.92	31.17*	18.83	52.83**
	(4.86)	(9.84)	(8.29)	(9.61)
ARCI				
Sedation	0.00	4.58**	0.50	1.67
	(0.49)	(1.12)	(0.82)	(0.89)
Euphoria	−0.17	0.17	0.75	3.75**
	(0.27)	(5.17)	(0.77)	(0.97)

Note. DSST = Digit Symbol Substitution Test, DEQ = Drug Effects Questionnaire, ARCI = Addiction Research Center Inventory.

* Significantly different from preplacebo or preethanol baseline at $p < .05$ according to Wilcoxon signed-ranks matched-pairs *t* test.

** Significantly different from preplacebo or preethanol baseline at $p < .01$ according to Wilcoxon signed-ranks matched-pairs *t* test.

Table 3

Pearson product-moment correlation coefficients for estimates of the *k* and *h* parameters in discounting functions and scores of impulsivity in personality measures.

Personality measures	Discounting	
	Delay [ln(*k*)]	Probability [ln(*h*)]
Impulsiveness-Venturesomeness-Empathy Questionnaire		
Impulsivity scale	0.14	0.21
Eysenck Personality Inventory		
Impulsivity scale	0.35*	0.36*
Extroversion scale	0.36*	0.44**
Sensation Seeking Scale		
Disinhibition scale	0.45**	0.40**

* $p < .10$.
** $p < .05$.

ual-subject scores on the various personality measures are listed in Appendix G.

DISCUSSION

The results of this study add to those from previous studies on measures of impulsivity in four ways. First, the study illustrates the superiority of a hyperbolic function to describe discounting by delay and probability in humans. Second, by examining discounting by delay and probability simultaneously within the same participants, we showed that there was a positive relationship between discounting for these two variables. Third, it was found that delay and probability discounting as measures of impulsivity were positively correlated with scores obtained on some standard personality questionnaires. Fourth, alcohol had no effect on delay or probability discounting.

Hyperbolic Versus Exponential Models of Discounting

Curve-fitting analyses showed that the discount functions in this study were best described by a hyperbolic function. When both hyperbolic and exponential models were fitted to the obtained delay and probability discount curves, the hyperbolic models accounted for more of the variance than the exponential models. The exponential models overestimated the reward values at short delays and high probabilities and underestimated them at longer delays and lower probabilities. This was true both for individual subjects' functions and for the group data.

The better fit of the hyperbolic rather than exponential function is consistent with previous reports with both delayed rewards and probabilistic rewards (Myerson & Green, 1995; Rachlin et al., 1991; Raineri & Rachlin, 1993). Whereas the hyperbolic model predicts that reward value decreases rapidly at short delays and more slowly at longer delays, the exponential model predicts a constant rate of decrease in value with delay. The hyperbolic model not only provides a better fit to the present and previous data, but it also accounts for preference reversals that sometimes occur as the time to an anticipated reward elapses (Kirby & Herrnstein, 1995; Myerson & Green, 1995). For example, if an individual is given a choice between two future rewards of unequal size, the smaller of which is available sooner than the larger, the individual might initially choose the larger, more distant, reward. However, as time passes and the availability of the smaller reward becomes imminent, the individual may then prefer the smaller, more immediate reward. The changing rate of discounting in the hyperbolic model accounts for this reversal because it predicts that the discount functions for the smaller, less distant reinforcer and for the larger, more distant reinforcers will cross as the delay to choice decreases, whereas the constant rate of discounting in the exponential model does not. Data suggest that similar reversals of preference may also occur in choices between probabilistic outcomes (Rachlin et al., 1987). Thus, if the reward probabilities for two probabilistic choices are increased by the same probability, there may be a reversal of preference between the two alternatives.

Within-Subject Comparison of Probability and Delay Discounting

It has been hypothesized that the processes that underlie discounting by delay and probability are fundamentally the same (Logue, 1988; Mischel & Grusec, 1967; Rotter, 1954). The present study provided some support for this idea. We observed marked individual differences in discounting of both delay and probability, and the participants who exhibited the greatest discounting of delayed rewards also exhibited the greatest discounting of probabilistic rewards (i.e., the k value for delay and the h value for probability were positively correlated). Despite the theoretical reasons for supposing that discounting by delay and probability is fundamentally the same, however, this idea leads to an apparently counterintuitive prediction. Individuals who appear to prefer low-probability rewards are sometimes referred to as ''risk prone,'' whereas those who avoid low-probability rewards are ''risk averse'' (Caraco, Martindale, & Whittam, 1980; Kahneman & Tversky, 1979). For example, risk-prone individuals should be relatively more likely to gamble on a low probability of obtaining a reward than are risk-averse individuals. In a procedure such as that used in the current study, this difference should result in risk-averse participants having lower indifference points for a given probability than risk- prone participants, thus showing steeper discount functions than risk-prone participants. Thus, if delay and probability are fundamentally the same process, participants who are less willing to wait in the delay procedure should also be *less* likely to gamble. Interestingly, this does not fit with our intuitive notions of ''impulsive'' individuals. The intuitive notion also does not fit with the data obtained in this study in which participants who discounted delay more steeply were less likely to take risks on the probabilistic choices.

Rachlin (1990) tried to reconcile the counterintuitive prediction of the delay-probability equivalence hypothesis described above by suggesting that some risk-prone behavior, such as compulsive gambling, may be the product of a history of sparse reinforcement schedules. That is, behavior may appear to be

risk prone in individuals whose responding persists after extensive experience with low probabilities of reward (Ferster & Skinner, 1957). However, this account does not provide an obvious explanation for the associations between delay and probability discounting within individuals observed in our study.

Alternatively, our intuitive notion of expecting impulsive individuals to be more risk prone may be incomplete. That is, impulsive individuals may indeed be more likely to take risks, but only when the outcomes are negative (e.g., likelihood of losing money in a gambling situation), as opposed to positive (e.g., earning money, as in our study). Partial support for this line of reasoning is provided by a recent study by Fromme, Katz, and D'Amico (1997). In this study, young adults were asked to estimate the likelihood of a negative outcome resulting from engaging in risky activities (e.g., illicit drug use, sex without a condom). They found that alcohol consumption decreased the subjects' estimates of the probability of negative outcomes and did not affect estimates of the probability of positive outcomes. This suggests that future studies aimed at studying risk taking should investigate situations that involve delayed or uncertain negative reinforcers.

Association of Delay and Probability Discounting with Paper-and-Pencil Tests of Impulsivity

In the context of personality theory, impulsivity and risk taking have been defined as separate but often overlapping processes or traits (Eysenck, 1993; Zuckerman, 1993). *Impulsivity* is defined as a failure to take into account the consequences of actions (Eysenck, 1993), a definition that intuitively corresponds well with the discounting model. According to Eysenck, the trait of impulsivity is part of a larger personality dimension referred to as extroversion. *Risk taking* is defined by Zuckerman as a form of sensation seeking, which increases arousal. The induction of arousal is thought to be positively reinforcing in risk-prone individuals. The disinhibition scale of the SSS, in particular, is thought to describe a lack of sensitivity to normal social controls, and may be associated with social disinhibition in the form of drinking, partying, gambling, and sex. One of our goals was to determine whether impulsivity and risk taking, as measured by these personality tests, were related to delay or probability discounting in the procedure used in this study.

We found that there was a trend for positive correlations between the k values for delay and h values for probability discounting and scores on the impulsivity and extroversion scales of the EPI and the disinhibition scale of the SSS. Thus, for example, the individuals with the largest k values, who showed the greatest delay discounting in our procedure, also scored highest on personality measures that were empirically developed to identify individuals who behave impulsively. The magnitude of the correlations were modest and on the IVE did not reach statistical significance at either the .05 or .1 levels. Nevertheless, the findings are notable considering that, for a study examining personality measures, the number of participants was small. Moreover, few of the questions on the personality tests refer to discounting of future consequences. We feel that these results are important because these positive correlations provide the first evidence that discounting in a behavioral task is related to the personality constructs measured by paper-and-pencil tests of impulsivity, supporting the validity of the discounting model of impulsive behavior. Further experiments with additional participants are needed to determine the strength of the association between discounting on the behavioral task and personality measures of impulsivity.

Effects of Alcohol on Delay and Probability Discounting

Although alcohol produced the expected dose-dependent effects on BAL, psychomotor behavior, and self-report ratings, alcohol did not influence the delay or probability discounting functions. Consistent with previous studies (de Wit & Doty, 1994; Doty & de Wit, 1995), alcohol increased subjects' ratings on ''feel drug,'' ''feel high,'' and ''want more'' visual analogue scales. Ethanol impaired DSST performance at the low but not the moderate dose of ethanol, probably due to variability across participants. Inconsistent effects of ethanol on DSST have also been found in previous studies in this laboratory (Doty, Kirk, Cramblett, & de Wit, 1995; Doty, Zacny, & de Wit, 1994). The low dose of al-

cohol increased ratings of sedation, whereas a higher dose of alcohol increased ratings of euphoria and liking. The absence of an effect of this behaviorally active dose of alcohol on our laboratory measure of impulsivity is inconsistent with anecdotal reports that alcohol is associated with impulsivity (Duffy, 1995; Graham, 1980). This inconsistency could be due to characteristics of the subject sample, aspects of the test environment, or methodological details of the behavioral procedure. The intoxication-impulsivity association has been observed in specific populations, such as alcoholics and individuals with low central serotonin function (Linnoila et al., 1990; Virkkunen & Linnoila, 1990), and the effect may be less pronounced in normal healthy social drinkers. Alternatively, the intoxication-impulsivity association may be evident only under conditions of high conflict. Based on a review of 34 laboratory studies, Steele and Southwick (1985) concluded that the effects of alcohol on various social behaviors were greater when participants were tested under conditions of high conflict. *High conflict* here refers to responses that have both reinforcing and punishing consequences of substantial magnitude. More recently, Lau, Pihl, and Peterson (1995) reported that the effects of alcohol on aggression in humans were greater under higher provocation (i.e., when intensities of electric shock were higher). It may be that alcohol would have more pronounced effects on impulsivity in our procedure if the situation had involved more conflict (e.g., if it involved winning or losing larger amounts of money). Finally, two procedural considerations may also have contributed to the lack of an alcohol effect. In the present design, participants did not experience the delays and probabilistic outcomes during the experimental session, but made their choices based on their previous life experiences, presumably in the nonintoxicated state. It is possible that the effects of alcohol become apparent only when participants have direct experience with delayed and probabilistic rewards while intoxicated. Another methodological consideration concerns the sensitivity of the procedure to changes in subjects' performance. It is possible that over repeated testing on the procedure (i.e., practice, alcohol, and placebo sessions) the participants might have developed rules that prevented alcohol from affecting their decisions.

In summary, this study illustrates the use of an efficient, computer-based adjusting procedure to determine discount functions for delay and probability in humans. Consistent with previous studies with both laboratory animals and humans, delay and probability discount functions were hyperbolic, according to the model proposed by Mazur (1987). There were two novel findings regarding possible individual differences in impulsivity. First, there was a relationship between discounting by delay and probability: Individuals who exhibited the strongest discounting of delay also exhibited the strongest probability discounting. Second, the degree of discounting was modestly correlated with scores on paper-and-pencil tests of impulsivity. However, discounting was not affected by the administration of moderate doses of alcohol. Taken together, these results support the idea that the behavioral discounting procedure may be an efficient and sensitive measure of impulsive behavior and has potential for studying the effects of drugs.

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APPENDIX A

Values of *k* and *h* for each participant before and after administration of placebo and the low (0.5 g/kg) and moderate (0.8 g/kg) doses of ethanol.

	Placebo				Ethanol			
	Delay (*k*)		Probability (*h*)		Delay (*k*)		Probability (*h*)	
Participant	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Low dose								
1	0.002	0.002	1.244	1.130	0.002	0.002	1.135	0.931
2	0.020	0.019	0.688	0.699	0.018	0.018	0.859	0.920
3	0.030	0.028	1.451	1.458	0.021	0.019	2.597	2.025
4	0.015	0.015	0.884	0.884	0.017	0.017	0.884	0.884
5	0.004	0.004	0.325	0.326	0.004	0.006	0.811	0.866
6	0.000	0.000	0.209	0.226	0.000	0.000	0.208	0.174
7	0.082	0.087	1.140	1.140	0.010	0.012	1.140	1.140
8	0.296	0.449	7.685	7.420	1.716	1.570	18.778	4.402
9	0.009	0.006	1.891	1.423	0.009	0.010	1.938	1.418
10	0.001	0.001	0.719	0.961	0.001	0.001	0.865	0.728
11	0.004	0.004	1.344	0.964	0.006	0.005	1.013	0.929
12	0.004	0.003	0.924	1.097	0.009	0.007	1.620	1.642
High dose								
13	0.006	0.008	2.508	2.357	0.024	0.020	3.095	1.861
14	0.553	0.625	3.408	3.327	0.117	0.123	7.801	5.472
15	0.269	0.272	2.497	1.705	0.635	0.338	1.900	1.765
16	0.051	0.306	1.221	1.473	0.486	0.342	1.521	1.741
17	0.013	0.013	1.015	0.782	0.028	0.012	0.835	0.364
18	0.001	0.001	0.672	0.662	0.001	0.001	0.515	0.461
19	0.030	0.080	1.634	1.542	0.121	0.439	3.956	3.549
20	0.006	0.007	1.685	1.883	0.003	0.004	1.414	1.419
21	0.003	0.006	0.551	0.595	0.002	0.001	0.730	0.734
22	0.048	0.051	1.056	1.094	0.035	0.043	1.120	1.056
23	0.006	0.006	1.558	2.240	0.005	0.005	2.789	3.319
24	0.002	0.004	2.979	3.041	0.007	0.009	1.900	2.077

Note. Participants 1, 5, 9, 11, 12, 15, 18, and 19 were female; the remainder were male.

APPENDIX B

Delay indifference points for each participant before and after administration of placebo and the low (0.5 g/kg) and high (0.8 g/kg) doses of ethanol. The values in the table are in dollars. The delays are in days (2, 30, 180, 365). The zero-delay point is not included because it was always equal to $10.00.

	Placebo								Ethanol							
	Pre				Post				Pre				Post			
Participant	2	30	180	365	2	30	180	365	2	30	180	365	2	30	180	365
Low dose																
1	9.25	7.75	7.25	6.75	8.50	7.00	7.00	6.75	8.25	7.50	7.25	5.75	7.75	6.75	7.50	6.00
2	9.75	7.75	0.75	0.25	9.75	8.00	0.75	0.25	9.75	7.75	1.25	0.75	9.00	7.75	1.25	0.75
3	9.75	5.50	1.00	0.75	9.50	5.75	1.00	1.00	9.75	7.25	0.75	0.50	9.75	7.75	0.75	0.75
4	9.75	8.75	1.00	1.00	9.75	8.75	1.00	0.75	9.75	9.00	0.25	0.25	9.25	8.75	0.25	0.50
5	9.25	9.25	9.25	0.25	9.50	9.00	9.25	0.25	9.75	8.75	8.75	0.25	9.25	8.75	7.50	0.25
6	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	10.00
7	9.50	2.00	1.25	1.50	8.75	2.25	1.25	1.50	9.75	9.75	2.00	1.75	9.75	9.25	1.75	1.75
8	5.50	2.50	2.00	1.75	4.75	2.25	1.75	1.75	2.00	2.25	1.25	1.50	2.25	1.25	2.00	1.25
9	9.75	7.75	4.50	1.50	9.75	9.25	5.75	2.00	9.75	6.00	5.00	2.75	9.25	6.75	4.50	2.25
10	9.50	9.00	8.00	7.50	9.00	8.25	8.50	8.25	9.00	8.75	7.75	7.75	9.00	8.75	8.25	7.75
11	9.50	9.25	6.75	2.50	9.75	8.75	7.25	2.75	9.50	9.50	4.50	2.50	9.75	8.50	5.50	3.00
12	9.25	8.00	6.50	4.00	9.50	9.00	7.00	4.00	9.75	6.50	4.75	3.00	10.00	5.25	5.25	4.50
High dose																
13	7.75	7.75	4.50	4.50	9.00	7.00	4.50	3.00	8.75	3.75	5.00	1.75	8.00	6.00	2.50	2.00
14	4.50	1.50	0.75	1.25	4.00	2.50	1.25	1.00	8.75	1.50	0.75	0.75	7.75	2.25	0.75	0.75
15	6.75	0.50	0.25	0.25	6.50	1.00	0.25	0.25	4.25	1.25	0.25	0.25	5.75	1.50	0.25	0.25
16	7.50	3.75	2.25	2.00	5.25	3.00	2.25	1.25	4.75	1.75	1.00	0.75	5.25	2.50	2.00	1.00
17	9.75	5.50	4.25	2.75	9.75	5.75	3.50	3.25	9.75	4.50	2.75	1.75	9.75	6.75	3.75	1.75
18	9.75	9.75	8.00	6.50	9.75	9.50	7.75	7.00	10.00	9.75	8.25	7.75	9.75	9.50	7.75	7.50
19	8.75	3.75	3.75	2.75	8.50	2.25	2.50	1.75	8.00	1.75	1.75	1.25	5.00	1.50	1.75	1.50
20	8.75	7.75	5.00	3.75	8.00	7.00	4.75	3.75	8.75	8.25	6.75	4.50	8.75	8.50	5.50	5.00
21	9.75	8.75	6.25	4.50	9.25	9.00	4.50	3.50	9.75	9.25	6.25	7.00	9.50	9.00	8.00	6.75
22	9.50	3.25	1.75	2.75	9.25	3.25	2.00	1.75	9.75	3.75	2.75	2.25	9.50	3.50	2.50	1.75
23	9.75	9.75	3.75	3.25	9.75	9.75	3.75	3.75	9.75	9.75	4.50	4.25	9.75	9.75	4.25	4.25
24	9.75	8.75	7.25	5.75	9.75	8.00	5.75	4.00	9.75	6.75	4.75	3.50	9.75	7.25	4.50	2.25

APPENDIX C

Probability indifference points for each participant before and after administration of placebo and the low (0.5 g/kg) and high (0.8 g/kg) doses of ethanol. The values in the table are in dollars. The 1.0 probability point is not included because it was always equal to $10.00.

	Placebo								Ethanol							
	Pre				Post				Pre				Post			
Participant	.9	.75	.5	.25	.9	.75	.5	.25	.9	.75	.5	.25	.9	.75	.5	.25
Low dose																
1	8.25	7.50	3.75	3.00	8.50	8.25	3.75	2.75	9.25	8.25	3.25	3.00	9.50	8.50	3.75	3.50
2	9.75	8.25	5.75	3.25	9.75	8.50	5.50	3.25	9.75	7.75	5.25	2.75	9.75	7.75	5.25	2.25
3	9.50	7.25	3.75	1.00	9.25	7.25	4.00	0.75	7.50	4.75	3.75	1.25	7.75	6.75	3.00	1.00
4	9.25	7.75	5.25	2.75	9.25	7.75	5.25	2.75	9.25	7.75	5.25	2.75	9.25	7.75	5.25	2.75
5	7.25	7.00	7.00	6.50	6.75	7.00	6.75	6.75	6.75	6.75	6.75	3.25	7.00	6.50	6.75	3.00
6	9.25	9.00	7.50	6.75	8.75	8.25	7.50	6.75	9.25	8.50	7.75	6.75	8.75	8.75	7.75	7.25
7	8.75	7.25	4.75	2.25	8.75	7.25	4.75	2.25	8.75	7.25	4.75	2.25	8.75	7.25	4.75	2.25
8	5.00	2.50	2.50	1.25	5.00	2.50	2.75	1.50	2.50	2.00	2.00	1.50	8.25	2.50	1.50	2.25
9	7.50	5.75	3.25	3.50	7.00	6.75	4.75	2.25	7.75	6.00	3.25	2.50	9.00	6.00	4.00	3.00
10	8.75	7.25	5.75	4.00	8.00	7.00	5.00	3.75	8.50	6.75	5.50	3.75	8.75	7.50	5.75	3.75
11	8.00	7.50	4.25	1.75	8.75	8.00	4.75	2.75	8.50	7.75	4.75	2.75	8.75	7.75	4.75	3.25
12	9.25	7.75	5.00	2.75	8.75	7.25	4.25	3.25	9.75	6.00	3.00	2.75	6.50	7.50	4.00	1.50
High dose																
13	7.50	5.75	2.50	1.75	7.50	5.25	3.50	1.75	7.75	4.50	2.50	1.50	8.75	7.00	2.25	1.75
14	6.50	4.00	3.75	1.75	7.00	4.25	3.00	1.75	5.00	2.75	1.75	1.50	5.00	4.50	1.75	1.50
15	9.50	5.75	1.00	1.50	9.25	6.75	3.25	1.00	9.00	6.50	2.75	1.25	9.00	8.00	1.75	1.25
16	9.00	7.25	4.25	2.25	9.00	6.25	4.50	1.50	8.75	7.75	3.50	0.75	8.75	6.50	3.50	1.25
17	8.50	6.75	4.75	3.75	9.25	7.50	5.25	3.75	9.25	6.75	6.25	2.75	9.50	8.00	6.25	6.00
18	9.75	7.75	5.50	4.00	8.75	7.50	6.00	4.00	9.25	7.25	6.50	4.75	9.25	7.25	6.75	5.00
19	8.25	5.25	3.75	4.00	7.75	4.75	4.75	4.00	8.00	3.25	2.00	1.50	7.75	2.75	3.25	2.00
20	8.25	5.25	3.75	3.75	8.00	4.75	4.00	3.50	8.50	5.75	4.00	3.75	8.00	6.00	4.00	3.75
21	9.25	8.00	6.00	4.50	9.25	7.75	6.50	3.75	9.00	8.50	5.25	3.50	9.50	7.75	6.00	3.00
22	9.75	9.75	3.25	1.75	9.75	9.75	3.00	1.75	9.25	9.50	2.75	1.75	9.75	9.75	3.25	1.75
23	8.75	5.75	4.00	2.75	9.00	3.75	3.75	3.00	8.50	4.25	2.75	1.75	8.00	3.75	2.50	2.00
24	6.75	4.25	3.50	2.75	7.00	5.25	2.50	1.25	8.50	6.00	2.75	2.75	7.75	5.75	3.25	2.25

APPENDIX D

Results of ANOVAs of indifference points for each level of delay and probability (i.e., delay/prob factor), pre- versus postbeverage (i.e., drug factor). Eight separate analyses were conducted, including analyses for placebo and alcohol sessions in the low-dose group (n = 12) and high-dose group (n = 12).

	Delay (k)				Probability (h)			
	Placebo		Alcohol		Placebo		Alcohol	
Factor	F	p	F	p	F	p	F	p
Low dose								
Drug	0.047	.833	1.363	.268	0.047	.833	2.250	.162
Delay/prob	76.336	.000	47.451	.000	76.336	.000	96.303	.000
Interaction	0.055	.690	0.581	.678	0.055	.690	0.474	.755
High dose								
Drug	7.556	.019	0.002	.968	0.233	.639	2.708	.128
Delay/prob	57.206	.000	51.264	.000	119.317	.000	100.960	.000
Interaction	0.906	.469	1.574	.198	1.606	.190	0.667	.618

Note. In all the F tests the degrees of freedom were (1, 11) for the drug factor, (2, 44) for the delay (or probability) factor, and (4, 44) for the interaction between drug and delay (or probability).

APPENDIX E

Breath alcohol levels, performance on the Digit Symbol Substitution Test (psychomotor task) and the "feel drug" scale of the Drug Effects Questionnaire (DEQ) for each participant before and after administration of placebo and the low (0.5 g/kg) and high (0.8 g/kg) doses of ethanol.

Participant	Breath alcohol (mg/dl)				Psychomotor task				DEQ "feel drug"			
	Placebo		Alcohol		Placebo		Alcohol		Placebo		Alcohol	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Low dose												
1	0.000	0.000	0.000	0.061	66	65	67	62	0	11	0	91
2	0.002	0.002	0.000	0.059	61	61	65	59	0	45	0	68
3	0.000	0.000	0.000	0.002	54	52	55	52	0	26	0	50
4	0.000	0.000	0.000	0.081	40	37	39	35	0	2	0	81
5	0.000	0.000	0.000	0.024	52	55	57	53	0	0	0	78
6	0.000	0.000	0.000	0.029	54	56	59	56	0	6	0	76
7	0.000	0.000	0.000	0.052	57	55	52	52	0	0	0	50
8	0.000	0.000	0.000	0.048	77	75	76	59	0	7	0	75
9	0.000	0.000	0.000	0.020	65	61	65	55	0	0	0	50
10	0.000	0.002	0.000	0.028	73	72	73	69	0	49	0	70
11	0.002	0.002	0.000	0.072	59	60	58	56	0	31	0	83
12	0.000	0.000	0.000	0.060	60	68	52	52	0	0	0	50
High dose												
13	0.000	0.000	0.000	0.110	42	46	47	37	0	50	0	50
14	0.000	0.000	0.000	0.048	48	49	49	47	0	50	0	100
15	0.000	0.000	0.000	0.076	58	51	56	45	0	28	0	50
16	0.000	0.000	0.000	0.064	58	58	55	49	0	0	0	89
17	0.000	0.000	0.000	0.051	55	53	48	47	0	22	0	100
18	0.000	0.000	0.000	0.084	66	69	67	54	0	0	0	44
19	0.000	0.000	0.000	0.079	64	63	63	64	0	29	0	57
20	0.000	0.000	0.000	0.070	69	68	60	53	0	7	0	75
21	0.000	0.000	0.000	0.072	74	73	64	68	0	0	0	96
22	0.000	0.000	0.000	0.029	63	65	58	61	0	29	0	100
23	0.000	0.000	0.000	0.066	59	58	51	47	0	0	0	50
24	0.000	0.000	0.000	0.055	70	68	64	67	0	26	0	76

APPENDIX F

Scores on the like drug scale of the Drug Effects Questionnaire (DEQ) and the sedation and euphoria scales of the Addiction Research Center Inventory (ARCI) for each participant before and after administration of placebo and the low (0.5 g/kg) and high (0.8 g/kg) doses of ethanol.

	DEQ like drug				ARCI sedation				ARCI euphoria			
Participant	Placebo		Alcohol		Placebo		Alcohol		Placebo		Alcohol	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Low dose												
1	50	50	50	86	9	13	5	4	1	0	0	10
2	50	56	50	53	3	1	1	10	2	2	1	0
3	50	10	50	84	2	2	3	3	1	1	1	0
4	50	50	50	63	3	3	1	7	2	1	1	1
5	50	50	50	70	5	6	2	9	3	4	4	1
6	50	53	50	70	7	4	6	6	1	2	1	6
7	50	50	50	50	3	3	3	8	6	4	7	1
8	50	50	50	33	2	2	4	8	4	3	3	0
9	50	50	50	77	4	3	1	1	0	1	1	1
10	50	50	50	34	1	2	1	9	2	2	2	2
11	50	62	50	80	3	3	1	9	1	1	3	11
12	50	50	50	40	1	1	1	10	13	13	12	5
High dose												
13	50	50	0	74	2	5	2	2	4	1	6	5
14	50	76	50	90	3	3	3	3	2	2	2	7
15	50	50	50	86	5	5	3	5	2	2	2	3
16	50	50	50	77	3	4	3	7	3	2	3	4
17	50	33	50	63	1	7	2	1	7	8	5	10
18	50	50	50	55	5	6	4	3	3	2	1	6
19	0	50	50	98	7	4	1	11	6	7	11	12
20	50	48	50	79	2	6	2	5	2	2	2	14
21	50	50	50	65	5	4	3	2	1	1	6	11
22	50	76	50	87	9	6	6	7	3	9	6	8
23	50	50	50	56	2	3	3	5	1	1	2	6
24	50	66	50	61	9	6	6	7	3	9	8	13

APPENDIX G

Values of various personality measures for each participant. The measures are for the impulsivity scale of the Impulsiveness-Venturesomeness-Empathy Questionnaire (IVE), the impulsivity and extroversion scales of the Eysenck Personality Inventory (EPI), and the disinhibition scale of the Sensation Seeking Scale (SSS).

Participant	IVE impulsivity	EPI impulsivity	EPI extroversion	SSS disinhibition
1	7	2	11	4
2	5	3	7	5
3	2	3	13	4
4	5	2	7	2
5	3	4	11	1
6	7	3	7	2
7	7	5	10	0
8	13	9	18	7
9	16	6	15	6
10	8	5	13	5
11	15	4	15	3
12	13	7	18	4
13	8	2	9	4
14	3	3	12	6
15	8	4	14	7
16	13	5	12	6
17	1	4	15	1
18	4	1	8	4
19	17	7	19	4
20	5	3	8	5
21	15	7	17	5
22	14	4	14	7
23	9	3	13	6
24	9	4	15	1

Note. Maximum scores for the various tests: IVE impulsivity scale = 19, EPI impulsivity scale = 9, EPI extroversion scale = 24, and SSS disinhibition scale = 10. Larger values indicate greater impulsivity.