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The Conjunction Fallacy Under Probability and Betting Instructions

by

Ashley Ellen Sides

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE Master of Arts

APPROVED, THESIS COMMITTEE:

Daniel Osherson, Autry Professor of Psychology, Chair

James Pomerantz, Professor Psychology

Richard Grandy, McManis Professor Philosophy

Houston, Texas

May, 2000
ABSTRACT

The Conjunction Fallacy Under Probability and Betting Instructions

by

Ashley Sides

Researchers have tried to keep subjects from committing the conjunction fallacy since Tversky and Kahneman discovered it in 1983. Betting paradigms (Bar-Hillel, 1993) have been used to force subjects to use a mathematical interpretation of ‘‘probability’’, but past experiments have either not involved actual betting or have had subjects bet on fictitious situations. In the current experiments half of the subjects were asked to decide which of 2 statements (about future events) had a higher probability while the other half were asked which statement they would prefer to bet on (in view of an actual payoff). The hypothesis was that while subjects in the probability condition would commit the conjunction fallacy, those in the betting condition would not. This hypothesis was not supported—there was not a significant difference between the numbers of conjunction fallacies committed by subjects in the two conditions in either of two experiments.
Acknowledgements

I would like to thank my Masters Committee for helpful comments and suggestions on this research. I would also like to thank Karin Dudziak, Denise Wu, Zhihua Tang, and Andrew Klager for helping to design stimuli and run subjects for these experiments.
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The Conjunction Fallacy Under Probability and Betting Instructions

The conjunction fallacy has often been cited as an example of the poor probabilistic reasoning techniques used by college students (Tversky & Kahneman, 1983; Thuring & Jungermann, 1990; Jones, Jones, & Frisch, 1995; Shafir, Smith, & Osherson, 1990), statistical (Nahinsky, Ash, & Cohen, 1987) and medical experts (Tversky & Kahneman, 1983; Wolford, Taylor & Beck, 1990), and children (Davidson, 1995). Since Tversky and Kahneman (1983) discovered that people sometimes believe that a conjunction is more likely than one of its conjuncts, this phenomenon has been studied in many different ways. Researchers have employed various techniques to try to help their subjects avoid the conjunction fallacy trap, but there is always some considerable percentage of subjects who continue to select the conjunction as the more probable statement (Tversky & Kahneman, 1983; Shafir, Smith & Osherson, 1990; Hertwig, Chase & Gigerenzer, 1997).

Tversky and Kahneman (1983) presented subjects with many probability problems, including the most famous conjunction fallacy problem—the “Linda” problem. In this problem subjects were presented with a description of a woman named Linda. This description functioned as the evidence (E) on which subjects were later asked to make judgments about Linda.

(E) Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in antinuclear demonstrations.

Subjects were then asked to rank order a number of statements by the probability that they were true about Linda. Included in the eight statements were:

(B) Linda is a bank teller. and
(B&F) Linda is a bank teller and is active in the feminist movement.

Given a mathematical interpretation of the word “probability”, the subjects should have ranked the former statement as more likely than the latter since it is impossible for Linda to be a feminist bank teller without also being a bank teller. However, the description of Linda that was presented to the subjects led them to the conclusion that Linda was likely a feminist, and so they tended to rank the feminist bank teller option as more likely than the bank teller option. Tversky and Kahneman (1983) found this sort of reasoning in a variety of logical problems, including medical judgments made by doctors, predictions by undergraduate students about the 1981 Wimbledon finals, and problems in which undergraduate subjects placed bets as to which series of results was most likely to occur during the repeated rolling of a regular six-sided die.

Many of the problems presented to subjects by Tversky and Kahneman (1983) and in replications of their work by others (Wolford, Taylor & Beck, 1990; Bar-Hillel & Neter, 1993) asked subjects to rank order the probability of many different statements or possible outcomes. A conjunction fallacy was said to have occurred any time a subject ranked a conjunction as more probable than one of its conjuncts. One possible reason for the high number of conjunction fallacies discovered in these studies is that subjects may not have compared each of the answer choices to all of the other ones, and therefore subjects may not have realized that two of their choices were a conjunction and its conjunct. Also included in the original Tversky and Kahneman (1983) work, however, were conditions in which subjects were presented with only two choices (a conjunction and one of its conjuncts) and asked which was more probable. In these experiments, subjects still committed the conjunction fallacy up to 85% of the time. This leads to the
conclusion that while subjects not noticing the relationship between two of the alternatives may have been responsible for some instances of the conjunction fallacy, it was not the only factor affecting the rate with which they committed the conjunction fallacy.

One interesting finding with regard to the conjunction fallacy is that familiarity with statistics does not protect people from error (Nahinsky, Ash, & Cohen, 1987; Tversky & Kahneman, 1983; Wolford, et al., 1990). This suggests that perhaps subjects in these studies have not been miscalculating the actual probabilities of events, but rather they have not been interpreting the word "probability" to mean mathematical likelihood. The word "probability" can be understood to mean a number of different things (Hertwig & Gigerenzer, in press), including evidential support. The strict mathematical interpretation (by which a person assigns a number between 0 and 1 to the likelihood that an event occurs) is only one possible interpretation of the word "probability" that subjects may have used.

Evidential support, or confirmation, is often defined in the following way: a statement X supports a statement Y to the extent that Pr (Y|X)\(^1\) exceeds Pr (Y). One way to measure the relationship between those two probabilities is by use of the quotient Pr (Y|X)/Pr (Y). If this definition of support is used, then E supports B&F more than E supports B if and only if

\[ (*) \quad \frac{Pr (B&F | E)}{Pr (B&F)} > \frac{Pr (B|E)}{Pr (B)} \]

Applying Bayes' theorem to each side of the inequality yields:

\(^1\) Pr (Y|X) refers to the conditional probability of Y given X.
\[
\frac{Pr(B\&F \mid E)}{Pr(B\&F)} = \frac{Pr(E \mid B\&F) \times Pr(B\&F)}{Pr(B \& F) \times Pr(E)} = \frac{Pr(E \mid B\&F)}{Pr(E)}, \text{ and}
\]

\[
\frac{Pr(B \mid E)}{Pr(B)} = \frac{Pr(E \mid B) \times Pr(B)}{Pr(B) \times Pr(E)} = \frac{Pr(E \mid B)}{Pr(E)}
\]

Hence, (*) holds if and only if

\[
\frac{Pr(E \mid B\&F)}{Pr(E)} > \frac{Pr(E \mid B)}{Pr(E)}
\]

which holds if and only if \( Pr(E \mid B\&F) > Pr(E \mid B) \). This is certainly possible, since Linda is more likely to be single, outspoken, etc. if she is a feminist bank teller than if she is just a bank teller.

Another possibility is that subjects are trying to maximize informativeness by giving as much information as possible. People who are engaged in cooperative conversations often make an effort to increase communicative efficiency (Politzer, 1985). That is, if there are two different things that could be said to describe a certain situation, person, etc., the one that should be said is the one that passes on the most information to the listener. People converse in order to pass on information, and if more information can be passed on in a short amount of time, then that is the cooperative thing to do. Therefore, in the Linda argument, subjects may believe that the probability of Linda being a feminist bank teller is so close to the probability that she is a bank teller that the former (more informative) statement is the correct one to make. It passes on substantially more information at relatively little cost (in terms of both time and likelihood of accuracy), therefore if a subject wanted to communicate what he or she knew about Linda then the “feminist bank teller” statement would be the more cooperative statement to make.
If the above assessment of the conjunction fallacy is correct then much of the previous research on the conjunction fallacy has found not necessarily that people are bad at estimating probability, but that people tend to confuse the concept of probability with the concept of evidential support or communicative efficiency. If this is the case then we should expect to see a decrease in the number of conjunction fallacies committed when stimuli are constructed in such a way that the correct (mathematical) meaning of the word “probability” is implied by the question. Researchers have done this in different ways: One study, conducted by Fiedler (1988) asked subjects to estimate “how many out of 100 people who are like Linda” could be described by different statements including B and B&F. This kind of frequency problem lends itself to the mathematical interpretation of the word “probability” rather than to the support interpretation. Further, Hertwig and Gigerenzer (1997) found that the number of conjunction fallacies committed by subjects was 20 percentage points less when subjects were asked to assign a probability estimate to each statement rather than to rank order the probability of the statements. These findings support the idea that people may not be as logically inept as the original work on the conjunction fallacy implies. Instead the problem may have been that subjects were answering a slightly different question than experimenters were asking.  

One method that has been suggested to force subjects into a mathematical (rather than evidential support or communicative efficiency) interpretation of the word “probability” is betting (Tversky & Kahneman, 1983; Wolford, et al., 1990). If subjects

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2 Wolford et al. (1990) have claimed that the conjunction fallacy might not be a fallacy. Their argument seems to move in the opposite direction of the conjunction fallacy, however. It supports the idea that conjunctive evidence makes a given conclusion more likely than does the evidence provided by just one of the conjuncts. That is not the point being argued by researchers who study the conjunction fallacy. The point of the conjunction fallacy is not about the support provided by the evidence; it is instead concerned with the fact that a conjunction cannot be more likely than one of its conjuncts. See Bar-Hillel (1991) and Wolford (1991) for further discussion of this topic.
are asked to bet on which potential outcome they think is more likely to occur then they should use a mathematical interpretation of the word “probability”. In the Linda problem, for example, if a subject were told that he or she should select a statement on which to bet (i.e., the subject would receive some amount of money if the statement he or she selected was true) then it should be clear that the conjunct was a better bet than was the conjunction. Betting on the conjunction in this case would be foolish—regardless of the information given in the evidence, the goal here is clearly to select a statement that is more likely to be true and therefore result in a payoff.

The betting paradigm has been used before to study the conjunction fallacy (Tversky & Kahneman, 1983; Wolford, et al. 1990), but without a real payoff. In other words, participants were asked to imagine that they were placing a bet rather than to actually place one. This may lead subjects to select a mathematical interpretation of the word “probability”, but it is not as convincing as a context in which subjects actually place a bet. Bar-Hillel and Neter (1993) conducted an experiment in which participants could win money if they correctly guessed which of seven statements was true about a fictitious person or situation. They used this betting paradigm to study the inclusion fallacy (the error of attaching greater probability to a subset compared to its superset). Subjects were given a description of a person, place or situation and then they chose which option they would prefer to bet on. Two or more of the choices for each question would have the set-subset relationship to each other. For example, after reading the following description of Danielle subjects “bet” on which of a list of seven options she was most likely to study:
Sensitive and introspective. In high school she wrote poetry secretly. Did her military service as a teacher. Though beautiful, she has little social life, since she prefers to spend her time reading quietly at home rather than partying.

In addition to filler items, the list included the choices literature, humanities, physics, and natural sciences. In this case the choices “literature” and “humanities” were the target answers because they were the choices suggested by the evidence; the choices “physics” and “natural sciences” functioned as distractors because while they have a set/subset relationship, neither one is suggested by the evidence. While the information given may have provided support for the more specific answer (literature, in this example), the better bet was always the broader category (humanities). This general answer would always allow subjects to win if the specific answer was correct, and would sometimes allow subjects to win in cases in which the specific answer was incorrect. In the above example, for instance, if a subject selected the broader category humanities, then he or she could win if the subject was literature, philosophy, or any other specialty in the field of humanities. Bar-Hillel and Neter (1993) found that the inclusion fallacy was committed about twice as often in cases where the category and its superordinate were targets than when the same pair of choices were distractors. For example, “literature” was about twice as likely to be selected over “humanities” as Danielle’s major in the above example than it was in a problem where subjects were asked to bet on the major of Oded, whose description led to the conclusion that he was probably a physics major. The choices were the same for subjects in both the Danielle and the Oded problem. This leads to the conclusion that when a category is highly likely (like the “literature” response in the problem described above) people tend to prefer a narrower category, but that when the situation is unlikely (for example, that Danielle would be a physics major rather than
a natural sciences major given her description) people prefer to bet on the broader
category. This pattern of results makes sense if probability is interpreted as
"communicative efficiency". because if Danielle is likely to be a literature major given
her description then precision is gained without much risk to accuracy if a subject says
that she is a literature major. If, however, she looks very little like a student majoring in
physics then subjects prefer to increase the chances of accuracy. In this case little
precision is gained (since it is unlikely that Danielle is a natural sciences major at all,
much less a physics major in particular) and there is a good chance of losing accuracy by
being too specific.

The Bar-Hillel and Neter (1993) study presented the material in a betting context
in which subjects should have used the mathematical interpretation of the word
"probability" rather than the support interpretation. Their experiment provided subjects
with an unusual set of situations on which to bet, however. In their experiment subjects
placed bets on outcomes that were already known (and in fact created) by the
experimenters. This is not the context in which betting usually takes place. While they
did make use of the betting paradigm in a way that led subjects to use a mathematical
interpretation of the word "probability", they did not use the standard betting situation in
which a person bets on the future (unknown) outcome of a familiar situation. Therefore,
this method of betting may have resulted in subjects selecting an alternative that is more
informative rather than more likely in an effort to satisfy the experimenters.

The experiment reported here, therefore, compared the number of conjunction
fallacies committed by subjects in two different conditions (probability and betting). We
studied the conjunction fallacy rather than the inclusion fallacy because, while these
errors are based on the same principle, the conjunction fallacy is more transparent. It is possible that subjects do not realize the set/subset relationship of literature and humanities, for example, but it is unlikely that a subject reading two sentences with the conjunction/conjunct relationship does not notice the overlap (since the overlap is apparent even at the linguistic level). All subjects were presented with two possible outcomes for each of 24 given situations. These situations were future events that were not under the control of the experimenters. In some cases the two choices consisted of a conjunction and one of its conjuncts. While participants in the probability condition were simply asked to select the event for each question that they believed was more likely to occur, participants in the betting condition were asked to choose which event under each question they preferred to bet on. Participants in the betting condition had the potential to actually receive $50 if the event that they selected for a given question actually occurred. Because participants were presented with only two choices for each question it seems likely that they were able to notice that the choices included a conjunction and one of its conjuncts. Based on the results of the Bar-Hillel and Neter (1993) study, since the choices were both unlikely, we expected subjects to choose the broader statement (i.e., the conjunct rather than a conjunction). Because participants in the betting condition were able to receive money if they chose an event that actually occurred, we expected them to use a mathematical interpretation of the word “probability” rather than evidential support or communicative efficiency interpretations. And because participants were betting on familiar situations, the outcomes of which were not controlled or known by the experimenters, we expected the betting procedure to result in subjects carefully considering the two alternatives and selecting the one that had the higher probability of
occurring rather than the one that was better supported or the one that maximized informativeness. We were shocked when that did not happen, and in fact subjects in both conditions selected the conjunction over one of its conjuncts the same number of times.

Experiment 1

Hypothesis

Based on previous work on the conjunction fallacy we expected people in the probability condition to commit the conjunction fallacy with some regularity. We expected instances of the conjunction fallacy in the betting condition to be nonexistent or very rare.

Method

Participants. Eighty-nine undergraduate students from Rice University participated for partial fulfillment of course requirements. In all, 44 students participated in the probability condition and 45 students participated in the betting condition. Sessions were run with 12-40 subjects at a time (which resulted in 6-20 subjects in each room).

Design. This experiment was run between-subjects, and the data were analyzed by t-test.

Materials. Experiment booklets were composed of 24 pages with instructions and one item on each page. Each booklet contained nine conjunction test items (CT), nine conjunction distractor items (CD), and six non-conjunction distractor items (ND). Conjunction test items required subjects to choose between two events of the type \( Y \& X \), \( X \), for example
• (Y&X) The percentage of American households with a computer will increase by at least 25% and World Wide Web usage will double from September 1, 1998 to September 1, 1999.
• (X) World Wide Web usage will double from September 1, 1998 to September 1, 1999.

These conjunction test items were the items of interest. The other two types of items served as fillers to mask the purpose of the experiment. Conjunction distractors required subjects to choose between two events of the type X, Y&Z:

• (Y&Z) Faith Hill will win the Country Music Award for best female vocalist and Garth Brooks will win the Country Music Award for best male vocalist in 1999.
• (X) Shania Twain will win the Country Music Award for best female vocalist in 1999.

The non-conjunction distractors required subjects to choose between two events of the type X, Y:

• (X) Bill Clinton will announce his intention to seek a divorce before September 1, 1999.
• (Y) By September 1, 1999 Janet Reno will announce her intention to run for the Presidency.

By the type of an item, therefore, we refer to its structure—conjunction test item (X, Y&X), conjunction distractor item (X, Y&Z), or nonconjunction distractor item (X, Y).

The same instructions appeared at the top of each page of the booklet. For participants in the probability condition the instructions read

Please place an X next to EXACTLY ONE event on this page: the one you think is most likely to occur. In other words, place an X next to the event that you believe has the highest probability of occurring.

Participants in the betting condition saw the following instructions:

Please place an X next to EXACTLY ONE event on this page: the one that you would like to bet on. In other words, place an X next to the event that you would
like to receive $50 for if you are selected to be eligible for the prize based on this question and this event actually occurs.

Participants in both the betting and the probability conditions were presented with the same 24 items. The only difference between the booklets for the two conditions were the instructions printed at the top of each page.

Participants were presented with booklets made up of 24 items, individually randomized under the constraint that the item types appear in the order shown in Appendix A. The two choices on each page were events that may or may not have occurred by a given date, usually between three and six months in the future (see Appendix B for actual items). Every effort was made to use the same items throughout the testing phase of this project, but the nature of the items was such that some of them "expired" (i.e., an event mentioned in one choice either occurred or became impossible between testing sessions). All items that expired during testing were replaced by similar items (see Appendix C for replacement items).

Procedure. Participants were randomly divided into two groups. One group was assigned to the probability condition and the other to the betting condition. The two groups were run in two separate rooms.

Participants in the probability condition were told that we wanted to know what people thought about the probabilities of future events. They were asked to look at each item in their booklets and decide which of the pair of events described on that page they believed was more likely to occur. They were instructed to proceed through the booklet at their own pace and mark the event on each page that they believed was more likely to occur.
Participants in the betting condition were told that we wanted to know how people bet on future events. The betting procedure was explained to these participants (see below) and then subjects proceeded through their booklets in the same way as subjects in the probability condition. After all participants in a given session completed their booklets, we collected an index card from each person. On the cards subjects recorded both a name and an email address at which they could be reached in six months. We then selected one index card (and therefore one participant) at random. We also selected a page from the experimental booklet at random. This item was designated for the bet, and the selected subject was informed that he or she would win $50 if the event s/he marked on the selected item occurred by the date mentioned in the item. Every subject and every item stood a chance of being selected for the bet, and it was impossible for participants to know before they finished their booklets which bet would actually be placed. This should have resulted in each subject responding to each item as if it was the one selected for the bet. No subject stood to lose any money in this experiment (if the event did not occur then no money would be transferred), but there was a distinct possibility that a subject could win the $50. To make this point salient, a $50 bill was presented at the beginning of the experiment and throughout the instruction period. The amount of the bet was also included in the written instructions for the task and as a result appeared at the top of each page in the experiment booklet. Neither the oral nor the written instructions for participants in the betting condition mentioned the word “probability”.

Results

In the probability condition, 38 of the 44 subjects committed the conjunction fallacy at least once. Each subject had nine opportunities to commit the conjunction
fallacy, and the average number of errors per subject was 3.5 (SD=2.52). Thirty-six of the 45 subjects in the betting condition committed the conjunction fallacy at least once, with an average of 3.2 (SD=2.37) errors per subject. The difference in means is not significant using a t-test. Table 1 shows the number of subjects who committed the conjunction fallacy \( m \) times.

Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number of conjunction errors</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Probability (N=44)</td>
<td>6</td>
</tr>
<tr>
<td>Betting (N=45)</td>
<td>9</td>
</tr>
</tbody>
</table>

When the subjects are grouped according to whether they committed less than 4 errors vs. at least 4 errors the \( \chi^2 \) statistic does not reveal a reliable difference between the conditions. Therefore we can draw the conclusion that the subjects in the two conditions used similar mental processes to generate their responses. Reinforcing this impression is the reaction to the nine conjunction distractor items (of the type \( X, Y\&Z \)). The mean number of conjunction choices for the probability and betting conditions on those was 4.61 (SD=1.73) and 4.96 (SD=1.62), respectively. The difference does not approach significance by a t-test.

Experiment 2
Hypothesis

The hypothesis of this experiment was the same as that of Experiment 1. The number of conjunction fallacies committed by people in the betting condition was expected to be close to zero while the number of conjunction fallacies committed by people in the probability condition was expected to be substantial.

Method

Participants. Participants in Experiment 2 were 57 student volunteers from the University of Houston. Twenty-nine subjects participated in the probability condition and 28 were assigned to the betting condition. Students who participated received extra credit in their psychology courses. Subjects in this condition were run in groups of 3 to 14.

Design. This experiment was also a between-subjects design and the results were analyzed using a t-test.

Materials. The same materials that were used in Experiment 1 were used in Experiment 2. Items that expired and were replaced can be seen in Appendix C.

Procedure. The same method that was used in Experiment 1 was used in Experiment 2. Thus, Experiment 2 was a replication of Experiment 1 with a slightly different population of participants.

Results

In the probability condition, all 29 subjects committed at least one conjunction error, with an average of 5.93 (SD=1.60) out of 9 possible errors. In the betting condition, 25 of the 28 subjects committed at least one conjunction error, with an average of 4.82 (SD=2.63) errors per subject. The difference in means is not significant by a t-
test. Table 2 shows the number of subjects in each condition that made \( m \) errors. No grouping of the students according to whether they committed at least \( m \) fallacies yields a reliable \( \chi^2 \) statistic between the two conditions. Subjects in the two conditions also responded similarly to the nine filler conjunction items of form \( X \cdot Y \& Z \). The mean number of conjunction choices for the probability and betting conditions was 4.17 (SD=1.31) and 4.04 (SD=1.57), respectively.

Table 2

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number of conjunction errors</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Probability (N=29)</td>
<td>0</td>
</tr>
<tr>
<td>Betting (N=28)</td>
<td>3</td>
</tr>
</tbody>
</table>

A univariate ANOVA revealed significantly more conjunction fallacies committed at the University of Houston compared to Rice (\( F(1, 144) = 25.4, p<.001 \)), but no interaction with experimental condition. Combining the two studies, we observed an average of 4.48 (of 9 possible) conjunction errors in the probability condition (N=73, SD=2.49), and an average of 3.84 (of 9 possible) conjunction fallacies in the betting condition (N=73, SD=2.58). The difference does not reach statistical significance.

General Discussion
Our hypothesis going into this experiment was that people were not as irrational as earlier studies had claimed (Tversky & Kahneman, 1983; Bar-Hillel & Neter, 1993; Wolford, Taylor & Beck, 1990), but that people used a different interpretation of the word probability than experimenters intended. We believed that if we could force people into a mathematical interpretation of the word probability (through the use of a betting task), they would select a conjunct as more likely than a conjunction that contained it. Even if performance on the betting task was not perfect (as it should have been) we at least expected it to be significantly better than performance on the probability task, in which people were still free to interpret the word “probability” as evidential support, communicative efficiency, or another way that might lead them to believe the conjunction was the more reasonable response. This hypothesis was not supported, however, as people in the betting condition committed the conjunction fallacy as often as people in the probability condition. This held true across two different experiments with two different subject populations.

There are three possible reasons for subjects to have performed the same way in the betting and probability conditions. One possibility is that they did interpret the word “probability” to mean mathematical likelihood in the betting condition (and possibly the “probability” condition as well), but that they either failed to compute the probabilities or computed them incorrectly. If this is the case then it looks like people use faulty reasoning techniques and draw incorrect conclusions based on the evidence with which they are presented.

Another possible reason that we did not find a difference between the two groups is that the subjects in the betting condition may have still used an alternative
interpretation of the word “probability”. If this is the case then our attempt to manipulate subjects into using a mathematical likelihood interpretation of the word “probability” was not effective. If so, subjects clearly committed an error in their selection of strategies for approaching these problems, but it is still possible that if they had used the intended interpretation of the word “probability” they would have selected the conjunction as more likely than one of its conjuncts. This is supported by the findings of Fiedler (1988) and Hertwig and Gigerenzer (in press) that when asked to give mathematical responses (either frequency or probability estimates) subjects committed the conjunction fallacy substantially less often than they did when they responded to rank-order questions. A third possibility is that subjects found the expected utility of the bet to be minimal and therefore did not make the effort to calculate the probabilities in this experiment even thought they would have if expected utility was higher. Expected utility is measured by multiplying the probability of payoff by the amount of the expected payoff. Since the probability of payoff was low in these situations (due more to the unlikely nature of the questions than to the odds of being selected as the subject who could receive the money) and the amount of money that could be won was not terribly high, it is possible that subjects were not motivated to think in terms of mathematical likelihood. This is unlikely to have been the case, however, as students at Rice University are very motivated. In other experiments with these subjects they have performed very well on memory tasks under conditions in which they are provided with feedback in terms of points rather than money.

Subjects committed a reasoning error when they committed the conjunction fallacy in the betting condition. Whether it was because they miscalculated the relative
probabilities or because they selected the wrong strategy for approaching the problems remains to be seen. Future research on this topic could involve explicitly telling one group of subjects what we mean by "probability" and then measuring the rate with which they commit the conjunction fallacy compared to a control group who is allowed to interpret the problems on their own. If an experiment like that is done and there are no differences between the groups then we will know that people are not misinterpreting the word probability, they just do not correctly apply the rules of probability to conjunction problems.
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*Journal of Behavioral Decision Making, 10*, 21-32.
Appendix A

Order of Item Presentation

CD
ND
ND
CT
CD
CT
CD
ND
CT
CD
CT
CD
ND
CT
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ND
CD
CT

CD = Conjunction Distractor (choices X, Y & Z)
CT = Conjunction Test (choices X, Y & X)
ND = Nonconjunction Distractor (choices X, Y)
Appendix B

Items Used in This Study

Conjunction Test (CT) items.

- The percentage of American households with a computer will increase by at least 25% and World Wide Web usage will double from September 1, 1998 to September 1, 1999.
- World Wide Web usage will double from September 1, 1998 to September 1, 1999.

- The Volkswagen Beetle will be ranked in the top 10 cars in the September issue of Car and Driver magazine, and the first 9 months of 1999 will show record number of orders for Volkswagens in the United States.
- The first 9 months of 1999 will show record number of orders for Volkswagens in the United States.

- The Dow Jones Industrial Average will drop at least 4,000 points from its current value and by September 1, 1999 the national unemployment rate will double.
- By September 1, 1999 the national unemployment rate will double.

- The creation of a Women’s National Baseball League will be reported by the national media by September 1, 1999.
- The Women’s National Basketball Association (WNBA) will have record earnings and the creation of a Women’s National Baseball League will be reported by the national media by September 1, 1999.

- The collie breed’s popularity will increase by over 10% (as measured by total number of American Kennel Club registrations) from September 1998 to September 1999.
- A new movie will be released featuring the dog “Lassie” (the collie from the famous TV series of the 1950s) and the collie breed’s popularity will increase by over 10% (as measured by total number of American Kennel Club registrations) from September 1998 to September 1999.
Each year the magazine *US News and World Report* (USNWR) rates colleges and universities, and reports changes in the schools over the past year.

- In the Fall 1999 issue of USNWR, Rice will be ranked among the top ten universities.
- The percentage of Rice University faculty in the National Academy of Sciences will increase and in the Fall 1999 issue of USNWR, Rice will be ranked among the top ten universities.

- The cigarette tax in Texas will increase by $1.00 per pack and the percentage of adolescent smokers in Texas will decrease at least 15% from current levels by September 1, 1999.
- The percentage of adolescent smokers in Texas will decrease at least 15% from current levels by September 1, 1999.

- By September 1, 1999 an experimental vaccine for childhood leukemia will be announced.
- The National Institute for Health (NIH) will increase spending on vaccine development by 50% in the first nine months of 1999 and by September 1, 1999 an experimental vaccine for childhood leukemia will be announced.

- Stock in Microsoft will increase in value by at least 15% between now and September 1, 1999.
- Microsoft will release a beta version of Windows 2000 by summer 1999 and stock in Microsoft will increase in value by at least 15% between now and September 1, 1999.

**Conjunction Distractor (CD) items.**

- Faith Hill will win the Country Music Award for best female vocalist and Garth Brooks will win the Country Music Award for best male vocalist in 1999.
- Shania Twain will win the Country Music Award for best female vocalist in 1999.

- The University of Houston writing department will be rated in the top 10% nationwide and will announce that it will expand its faculty by September 1, 1999.
- The University of Houston Philosophy Department will hire three new faculty members by September 1, 1999.
• A tornado will touch down in Houston in July 1999 and damage estimates will be over $50 million.
• More precipitation will be recorded in Houston in July 1999 than has been recorded in Houston in July any of the past 25 years (1974-1998).

• The New York Yankees will make it to the World Series again in 1999 and will win it in fewer than 6 games.
• The San Diego Padres will make it to the World Series in 1999.

• By September 1, 1999 Texas will start selecting juries from a pool of licensed drivers rather than registered voters and the number of registered voters will increase by 10%.
• By September 1, 1999 Texas will require people to pass a literacy test before serving on a jury.

• The new Star Wars movie will receive poor reviews in the Houston Chronicle by September 1, 1999.
• The new Star Wars movie will outsell the previous three Star Wars movies combined and Burger King will market glasses with Star Wars characters on them by September 1, 1999.

• By July 1, 1999 public high schools in Houston, TX will announce a program to provide cab rides for all intoxicated teenagers celebrating New Year’s Eve.
• By July 1, 1999 the Texas chapter of Mothers Against Drunk Driving (MADD) will announce a program to offer cab rides to all intoxicated adolescents celebrating New Year’s Eve and the number of participants in MADD will double by October 1, 1999.

• The University of Houston will announce an automatic tuition waiver for students entering in the fall of 1999 who score over 1350 on the SAT, and the number of students who enroll in the University of Houston will increase by at least 10% from 1998.
• The University of Houston will enroll 15% more students from Fall 1999 than from Fall 1998.

• Burger King will outsell both McDonalds and Wendy’s nationwide between January 1999 and September 1999.
• One percent or more of McDonalds restaurants nationwide will fail their health inspections at least once between January 1999 and September 1999 and Burger King will outsell McDonalds during the same period.

Non-conjunction Distractor (ND) items.

• Bill Clinton will announce his intention to seek a divorce before September 1, 1999.
• By September 1, 1999 Janet Reno will announce her intention to run for the Presidency.

Clyde Drexler just retired from the Houston Rockets to coach the University of Houston basketball team.
• All season tickets for the University of Houston Cougars 1999-2000 basketball season will be sold out by September 1, 1999.
• Clyde Drexler will be offered a position as manager of an NBA team by September 1, 1999.

• Michael Chang will win the United States Tennis Association championship game, the US Open, in 1999.
• Tiger Woods will win the United States Golf Association championship game, the US Open, in 1999.

• Governor Bush will announce his withdrawal from the race for the Presidency before June 1, 1999.
• Al Gore will announce his withdrawal from the race for the Presidency before June 1, 1999.

• Fidel Castro will be removed from political power in Cuba by September 1, 1999.
• US forces will be sent to Havana, Cuba before September 1, 1999.

• North Korea will surrender to South Korea by September 1, 1999.
• North Korea will announce an underground nuclear test by September 1, 1999.
### Appendix C

**Items That Expired During Testing**

**Conjunction Test Items.**

<table>
<thead>
<tr>
<th>Original Item</th>
<th>Replacement Item</th>
<th>Date of Replacement</th>
<th>Item Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>- It will be impossible to satisfy consumer demand for the newly introduced Volkswagen Beetle in the first three months of 1999, and the first six months of 1999 will show record number of orders for Volkswagens in the United States.</td>
<td>- The Volkswagen Beetle will be ranked in the top 10 cars in the September issue of Car and Driver magazine, and the first 9 months of 1999 will show record number of orders for Volkswagens in the United States.</td>
<td>4-16-99</td>
<td>CT</td>
</tr>
<tr>
<td>- The first six months of 1999 will show record number of orders for Volkswagens in the United States</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Each year the magazine <em>US News and World Report</em> (USNWR) rates colleges and universities, and reports changes in the schools over the past year.</td>
<td>Each year the magazine <em>US News and World Report</em> (USNWR) rates colleges and universities, and reports changes in the schools over the past year.</td>
<td>4-16-99</td>
<td>CT</td>
</tr>
<tr>
<td>- In the Spring 1999 issue of USNWR, Rice will be ranked among the top ten universities.</td>
<td>- In the Fall 1999 issue of USNWR, Rice will be ranked among the top ten universities.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- The percentage of Rice University faculty in the National Academy of Sciences will increase and in the Fall 1999 issue of USNWR, Rice will be ranked among the top ten universities.</td>
<td>- The percentage of Rice University faculty in the National Academy of Sciences will increase and in the Fall 1999 issue of USNWR, Rice will be ranked among the top ten universities.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original Item</td>
<td>Replacement Item</td>
<td>Date of Replacement</td>
<td>Item Type</td>
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<tr>
<td>------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>• Shania Twain will win the Grammy for the best female vocalist and Garth Brooks will win the Grammy for best male vocalist in 1999.</td>
<td>• Faith Hill will win the Country Music Award for best female vocalist and Garth Brooks will win the Country Music Award for best male vocalist in 1999.</td>
<td>2-18-99</td>
<td>CD</td>
</tr>
<tr>
<td>• Bruce Springsteen will win the Grammy for best male vocalist in 1999.</td>
<td>• Shania Twain will win the Country Music Award for best female vocalist in 1999.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| • For Houston, March 1999 will be the warmest on record in 50 years, and prescriptions for allergy medications will be at least 10% higher than in March 1998. | • A tornado will touch down in Houston in July 1999 and damage estimates will be over $50 million.  
• More precipitation will be recorded in Houston in July 1999 than has been recorded in Houston in July any of the past 25 years (1974-1998). | 4-16-99            | CD        |
| • It will snow in Houston during March 1999.                                 |                                                                                  |                     |           |
| • Tom Hanks will win a 1999 Oscar award and be featured in at least two new movies released between March 1, 1999 and September 1, 1999. | • The New York Yankees will make it to the World Series again in 1999 and will win it in fewer than 6 games.  
• The San Diego Padres will make it to the World Series in 1999.                   | 4-16-99            | CD        |
<p>| • Nick Nolte will win a 1999 Oscar award for his role in the movie Affliction. |                                                                                  |                     |           |</p>
<table>
<thead>
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<th>Date of Replacement</th>
<th>Item Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The new Star Wars movie will receive two thumbs down from Siskel and Ebert by September 1, 1999.</td>
<td>• The new Star Wars movie will receive poor reviews in the Houston Chronicle by September 1, 1999.</td>
<td>4-16-99</td>
<td>CD</td>
</tr>
<tr>
<td>• The new Star Wars movie will outsell the previous three Star Wars movies combined and Burger King will market glasses with Star Wars characters on them by September 1, 1999.</td>
<td>• The new Star Wars movie will outsell the previous three Star Wars movies combined and Burger King will market glasses with Star Wars characters on them by September 1, 1999.</td>
<td>4-16-99</td>
<td>CD</td>
</tr>
<tr>
<td>• The Texas chapter of <em>Mothers Against Drunk Driving</em> will sponsor a program to provide cab rides for all 1999 intoxicated prom-goers, and the number of alcohol-related accidents immediately following high school proms in Texas will decrease by 10%. Public high schools in Houston, TX will sponsor a program to provide cab rides for all intoxicated prom-goers in 1999.</td>
<td>• By July 1, 1999 public high schools in Houston, TX will announce a program to provide cab rides for all intoxicated teenagers celebrating New Year’s Eve. • By July 1, 1999 the Texas chapter of <em>Mothers Against Drunk Driving</em> (MADD) will announce a program to offer cab rides to all intoxicated adolescents celebrating New Year’s Eve and the number of participants in MADD will double by October 1, 1999.</td>
<td>4-16-99</td>
<td>CD</td>
</tr>
</tbody>
</table>
Rice University will announce an automatic 25% tuition waiver for students entering in the fall of 1999 who score over 1550 on the SAT, and the number of applications to Rice University will increase by at least 20% from 1998.

Rice University will accept 15% more students for Fall 1999 than from Fall 1998.

The University of Houston will announce an automatic tuition waiver for students entering in the fall of 1999 who score over 1350 on the SAT, and the number of students who enroll in the University of Houston will increase by at least 10% from 1998.

The University of Houston will enroll 15% more students for Fall 1999 than from Fall 1998.

Nonconjunction Distractor Items.

<table>
<thead>
<tr>
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<th>Replacement Item</th>
<th>Date of Replacement</th>
<th>Item Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>•The same movie will win the Oscars for Best Supporting Actor, Best Lead Actress, and Best Supporting Actress in 1999.</td>
<td>•Michael Chang will win the United States Tennis Association championship game, the US Open, in 1999.</td>
<td>4-16-99</td>
<td>ND</td>
</tr>
<tr>
<td>•By September 1, 1999 Titanic will lose its first place ranking in terms of overall box office receipts.</td>
<td>•Tiger Woods will win the United States Golf Association championship game, the US Open, in 1999.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>