

The conjunction fallacy: a misunderstanding about conjunction?

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Abstract

It is easy to construct pairs of sentences X , Y that lead many people to ascribe higher probability to the conjunction X -and- Y than to the conjuncts X , Y . Whether an error is thereby committed depends on reasoners' interpretation of the expressions "probability" and "and." We report two experiments designed to clarify the normative status of typical responses to conjunction problems.

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1. Fallacy or no fallacy?

Despite extensive debate lasting several decades, there is still no consensus among cognitive scientists on a fundamental question about human reasoning. Are many Western college students disposed to elementary errors when evaluating the chances of simple events? In the present note, we attempt to settle the matter with respect to the conjunction fallacy.

Let X and Y be the following English sentences (appearing as stimuli in Sides, Osherson, Bonini, & Viale, 2002).

- (1) X : The cigarette tax in Texas will increase by \$1.00 per pack by September 1, 1999.
 Y : The percentage of adolescent smokers in Texas will decrease at least 15% from current levels by September 1, 1999.

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Let *X-and-Y* denote the result of writing *X* followed by the word “and,” followed by *Y*. Sides et al. (2002) observed a majority of subjects preferring to bet on *X-and-Y* compared to *Y*. Likewise, a majority of a different set of subjects judged *X-and-Y* to have higher probability than *Y*.¹ Similar results were obtained for other items in several replications, which included measures to prevent *Y* from being misinterpreted as *Y-and-not-X*. (The possibility of such misinterpretation is raised in Dulany & Hilton, 1991; Macdonald & Gilhooly, 1990; Morier & Borgida, 1984; Politzer & Noveck, 1991; Tversky & Kahneman, 1983).

Concordant findings emerge from follow-up work reported in Bonini, Tentori, and Osherson (2004) using a different betting paradigm. We invited subjects to choose bets among all three of *X-and-Y*, *X*, and *X-and-not-Y*. The presence of *X-and-not-Y* as an explicit alternative makes it pragmatically impossible to interpret *X* as *X-and-not-Y* since it would be uncooperative to needlessly repeat one of the options in altered form. Different choices for *X* and *Y* appeared in different items. For example, one item read as follows.

Because of the Italian Rail’s new policies aimed at encouraging voyages longer than 100 km, the number of passengers . . .

will decline by 5% on commuter trains and increase by 10% on long distance trains.
[*X-and-Y*]

will decline by 5% on commuter trains and will not increase by 10% on long distance trains.
[*X-and-not-Y*]

will decline by 5% on commuter trains. [*X*]

Eighty percent of 60 Italian college students chose to bet some money on *X-and-Y*; in fact, the average bet on *X-and-Y* was significantly greater than the average bet on *X*. Of course, if the goal is to maximize expected winnings, all bets should have been placed on *X*. Other items yielded similar preferences. The bets were genuine, and subjects were informed that they could limit their bets to a single statement. Sixty additional students performed in the same way even when the conjunctive statements were accompanied by the parenthetical remark: “both events must happen for you to win the money placed on this bet.”

Thus (as originally reported by Tversky & Kahneman, 1983), for some choices of *X* and *Y*, many people endorse the inequality:

$$(2) \quad \text{Prob}(X\text{-and-}Y) > \text{Prob}(Y).$$

Moreover, it seems justified to understand the function $\text{Prob}(\cdot)$ in (2) as reflecting reasoner’s judgments about chance, rather than some other concept that might be encoded by the locution “probability.” For, no appreciable differences were found in Sides et al. (2002) experiments between the conditions in which subjects placed bets on statements versus comparing their probabilities; likewise, the experiments reported in Bonini et al. (2004) involved betting only.² The experiments thus conform to the recommendations of several commentators (e.g., Hertwig & Gigerenzer, 1999, p. 293) who advocate betting instructions as a means of circumventing ambiguity in the word “probability.” The procedures followed in Sides et al. (2002) and Bonini et al. (2004) also make it unlikely that reasoners tended to construe $\text{Prob}(X)$ as $\text{Prob}(X\text{-and-not-}Y)$ [and similarly for $\text{Prob}(Y)$]. It therefore seems safe to assume that participants endorse (2) literally, namely, as the attribution of greater probability to a conjunction compared to one of

its conjuncts. (See Bonini & Savadori, 2003, for additional experimental evidence in support of this claim.)

There remains the question: Is (2) a fallacy? From the theory of subjective probability (as presented, for example, in Skyrms, 2000, chapter VI), one derives the following principle:

(3) For all statements A, B , $\text{Prob}(A \wedge B) \leq \text{Prob}(A), \text{Prob}(B)$.

But (3) does not, by itself, contradict (2) inasmuch as $X \wedge Y$ fails to appear in (2); only X -and- Y appears. Thus is born the idea that (2) sustains no charge of fallacy except through illicit conflation of logical conjunction (\wedge) with natural language conjunctions like “and” (e.g., Gigerenzer, 2001, pp. 95–96). The conflation is illicit because “and” possesses semantic and pragmatic properties that are foreign to \wedge . For example, uttering X -and- Y often conveys temporal succession or even causation, as in “Bill ate garlic ice cream and died.” (For discussion, see Carston, 1993; Sweetser, 1990.)

Let us make the case that (2) is nonetheless a genuine conjunction fallacy. Suppose again that X and Y are as specified in (1). The reader will likely concur that:

(4) (a) It is impossible for X to be false given the truth of X -and- Y .
 (b) It is impossible for Y to be false given the truth of X -and- Y .

Indeed, we think that virtually every native speaker of English would agree with (4) even if she interprets X -and- Y as “ X and then Y ” or as “ Y because of X .” Now, obviously:

(5) It is impossible for $X \wedge Y$ to be false given the truth of the two statements X, Y .

Immediately from (4) and (5), it follows that:

(6) It is impossible for $X \wedge Y$ to be false given the truth of X -and- Y .

Using standard terminology, we can therefore say that the argument from X -and- Y to $X \wedge Y$ is *valid*. (See Skyrms, 2000, p. 17 and Hodges, 1977, p. 55 for this usage of “valid.”) Similarly, (4) shows that the arguments from X -and- Y to X , and from X -and- Y to Y are valid. Using \models to signify valid inference, we abbreviate these facts to:

(7) (a) X -and- $Y \models X$.
 (b) X -and- $Y \models Y$.
 (c) X -and- $Y \models X \wedge Y$.

Well-known analyses of the betting rates set by rational players lead to the (extremely reasonable) principle:

(8) For any statements A, B , $\text{Prob}(A) \leq \text{Prob}(B)$ whenever $A \models B$.

In view of (7b) and (8), a probability fallacy therefore results from believing (2). The only way to escape this conclusion is to deny that people believe (7b). Such denial strikes us as a desperate defense of human judgment, and is also contrary to the experimental results reported below.

We conclude that (2) is indeed a probabilistic fallacy. But does (2) qualify as a *conjunction* fallacy? Answering this question seems to involve little more than terminology; the important empirical issue is whether human judgment violates elementary principles of rational

personal probability, and this is demonstrated by the combination of beliefs (7b) and (2). The terminological issue may nonetheless be addressed as follows.

Let us first observe that the “official” conjunction fallacy

$$(9) \quad \text{Prob}(X \wedge Y) > \text{Prob}(Y).$$

is easily derived from (2) via (7c), (8), and the transitivity of numerical inequality.³ So (2) is either equivalent to (9) (if “and” means \wedge) or else strictly stronger than (9) (if “and” means more than just \wedge). Anyone endorsing (2) has therefore committed *at least* the official conjunction fallacy. Thus, the only reason to deny (2) the status of true conjunction fallacy is to insist that conjunction fallacies must endorse *exactly* (9) and nothing more.

To perceive the peculiarity of such insistence, recall how easily (7c) is derived from the self-evident facts in (4). The validity of the argument from *X-and-Y* to $X \wedge Y$, along with its simple demonstration, make it natural to affirm that $X \wedge Y$ is part of the meaning of *X-and-Y*, hence that *X-and-Y* expresses $X \wedge Y$. Such an affirmation does not require $X \wedge Y$ to *exhaust* the meaning of *X-and-Y*, since (7c) does not require that *X-and-Y* be logically equivalent to $X \wedge Y$ (i.e., that also $X \wedge Y \models X\text{-and-}Y$). Analogously, it is accurate to say that the Declaration of Independence expressed the desire of the colonies to be free of England; it is not thereby asserted that nothing more was expressed. That \wedge does not represent all linguistic uses of “and” as a sentential connective is familiar and uncontroversial; it has been observed in logic texts for half a century (Strawson, 1952, p. 80; Suppes, 1957, p. 5; Mates, 1965, chapter 5; Kleene, 1967, p. 64). This truism should not prevent us from recognizing the equally evident fact that *X-and-Y* expresses the logical conjunction $X \wedge Y$, *whatever else* *X-and-Y* happens to express. For example, given our choices of *X* and *Y*, it may be that *X-and-Y* expresses (or pragmatically implicates) that *X* is a cause of *Y*. Even so, *X-and-Y* also expresses $X \wedge Y$, as shown by (7c). Consequently, it is natural to assert that (2) expresses the (formal) conjunction fallacy (9).

It remains to show experimentally that many people endorse statements of form (2) at the same time that they agree to (7a, 7b).

2. Experiment I

2.1. Method

Fifty Italian students (mean age 22.7 years, 30 males) from the University of Padua were invited to choose the most probable statement from sets of three. Two such sets were as follows (translated from Italian).⁴

- (10) SCANDINAVIA PROBLEM: The Scandinavian peninsula is the European area with the greatest percentage of people with blond hair and blue eyes. This is the case even though (as in Italy) every possible combination of hair and eye color occurs. Suppose we choose at random an individual from the Scandinavian population. Which do you think is the most probable? (Check your choice.)
- The individual has blond hair.
 - The individual has blond hair and blue eyes.
 - The individual has blond hair and does not have blue eyes.

- (11) VOLLEYBALL PROBLEM: Professional volleyball players have greatly changed in the course of the last decade. In particular, they have grown younger yet taller. Women players in the first Italian division are on average taller than 1.80 m, ranging between 1.75 m for some setters to more than 1.90 m for many spikers. Suppose we choose at random a female volleyball player from the Italian first division. Which do you think is the most probable? (Check your choice.)
- The woman is less than 21 years old.
 - The woman is less than 21 years old and is taller than 1.77 m.
 - The woman is less than 21 years old and is not taller than 1.77 m.

Notice that both problems oppose statements of the forms X , X -and- Y , and X -and-not- Y . The two problems were inserted randomly among three others that presented options of the forms X , not- X -and- Y and not- X -and-not- Y . No fallacy is associated with any choice in the latter three problems, which served as “fillers” to mask the intent of the experiment. An example of a filler is:

FILLER ITEM: In the city of Florence there are many shops featuring crafts. Among them are shops with leather goods, jewelry, and art. Some of these shops are ample in size, and serve as schools with many apprentices. Others are smaller. Suppose we choose at random a crafts shop in Florence. Which do you think is the most probable? (Check your choice.)

- The shop sells leather goods.
- The shop does not sell leather goods and has fewer than two apprentices.
- The shop does not sell leather goods and has at least two apprentices.

After responding to the five problems, each participant answered two further questions designed to test conformity to (7a, 7b), above. They were as follows.

- (12) IMPLICATION QUESTION FOR THE SCANDINAVIA PROBLEM: Luke is in his last year of high school. One morning he met Mika, a new student from Finland. Mika has blond hair and blue eyes. Speaking together, Luca learned that Mika likes to play the piano and is in Italy because his father was transferred to the Milan branch of a large foreign bank.
- At home Luca tells his sister about Mika, and makes several claims about him. From among the statements shown below, please indicate which are true, which are false, and which might be either.
- (a) Mika was born in Helsinki.
 - (b) Mika hates to play the piano.
 - (c) Mika has blue eyes.
 - (d) Mika likes living in Milan.
 - (e) Mika has blond hair.
 - (f) Mika says that his family moves often because of his father’s work.

Each of (a)–(f) was followed by the three choices: *True*, *False*, *Might be either*. Notice that items (c) and (e) allow test of the claim that X -and- $Y \models X, Y$, for the X and Y appearing in the Scandinavian Problem (10). The other items were fillers. Similarly, the implication question corresponding to the volleyball problem was as follows.

- (13) IMPLICATION QUESTION FOR THE VOLLEYBALL PROBLEM: Simona works as a recruiter for a well-known modeling agency in Rome. One morning, she met Anita, a volleyball player in the first Italian division. Anita is less than 21 years of age and is taller than 1.77 m. Speaking together, Simona learns that Anita likes to travel and is looking for part time work when she is not in training.
- At home, Simona tells her sister about Anita, and makes several claims about her. From among the statements shown below, please indicate which are true, which are false, and which might be either.
- (a) Anita is looking for a job with long-term prospects.
 - (b) Anita is less than 21 years of age.
 - (c) Anita likes to travel to exotic places.
 - (d) Anita is taller than 1.77 m.
 - (e) Anita would like to change jobs.
 - (f) Anita lives in Rome.

Again, items (b) and (d) allow test of the claim that $X\text{-and-}Y \models X, Y$ for the X and Y appearing in the Volleyball Problem (11).

2.2. Results

Forty-five of the 50 participants responded with *True* to both crucial items in both implication questions [(12) and (13)], thereby showing agreement with the implications in (7). Of these 45 students, 29 failed in both the Scandinavia and Volleyball problems [(10) and (11)] to choose the X option as most probable; 38 of the 45 students failed to choose X in at least one of the two

Table 1
Choices in Experiments I and II

	Experiment	
	I	II
Scandinavia		
X	14	18
X-and-Y	23	21
X-and-not-Y	8	7
Total	45	46
Volleyball		
X	9	13
X-and-Y	33	29
X-and-not-Y	3	4
Total	45	46

Note. Only participants responding “true” to both crucial items in both implication questions are represented here. Twenty-nine participants committed conjunction fallacies on both problems in Experiment I; 38 committed the fallacy at least once. Twenty-six participants committed conjunction fallacies on both problems in Experiment II; 35 committed the fallacy at least once.

problems. The percentage of choices for *X*, *X-and-Y*, and *X-and-not-Y* are shown in Table 1. Note that *X-and-Y* was selected most. The hypothesis that *X-and-Y* had a one-third chance of selection in the Scandinavia problem was rejected by a binomial test ($p < .02$); the same hypothesis was also rejected in the Volleyball problem ($p < .001$).

These results suggest that a majority of our participants understood that *X-and-Y* implies *X* yet mistakenly attached greater probability to the former compared to the latter. We suspect (but cannot prove with the current data) that one reason *X-and-Y* appeared so probable was its juxtaposition with *X-and-not-Y*. Table 1 shows that the latter sentence was seldom chosen. (Similar speculation applies to the results of the next experiment.)

3. Experiment II

3.1. Frequency formats

The statements *X* and *Y* in (1) evoke no plausible reference class of events, so their estimated chances belong to the realm of subjective probability. It is sometimes denied that probabilities can be sensibly attributed to such statements (Gigerenzer, 2000, pp. 249–250), and therefore denied that a conjunction fallacy can arise for them. The status of subjective probability has been much debated among psychologists (see Gigerenzer, 1996; Kahneman & Tversky, 1996, and references cited there). For our part, we accept the familiar view that there are several kinds of probability, among them “personal” probabilities that apply to singular events and can be specified via betting rates (see Hacking, 2001).⁵

Whatever the status of subjective probability, it should be observed that the two problems (10) and (11) concern probability in the frequency sense since each involves random sampling from a finite population of relevantly similar cases. Tversky and Kahneman (1983) observed that reasoning about frequencies compared to singular events reduced (but by no means eliminated) conjunction fallacies. Experimental follow-up has largely confirmed their findings.⁶ To test the robustness of our results in Experiment I we therefore repeated it with wording that highlights the frequency interpretation of the questions.

3.2. Method

Fifty Italian students (mean age 22.9 years, 34 males) from the University of Padua faced modified versions of the problems used in Experiment I. The students were drawn randomly from the same pool used in Experiment I; none participated in both experiments. We illustrate the new wording using the two problems corresponding to (10) and (11).

- (14) SCANDINAVIA PROBLEM, FREQUENCY VERSION: The Scandinavian peninsula is the European area with the greatest percentage of people with blond hair and blue eyes. This is the case even though (as in Italy) every possible combination of hair and eye color occurs. Suppose we choose at random 100 individuals from the Scandinavian population. Which group do you think is the most numerous? (Check your choice.)

- Individuals who have blond hair.
- Individuals who have blond hair and blue eyes.
- Individuals who have blond hair and do not have blue eyes.

- (15) VOLLEYBALL PROBLEM, FREQUENCY VERSION: Professional volleyball players have greatly changed in the course of the last decade. In particular, they have grown younger yet taller. Women players in the first Italian division are on average taller than 1.80 m, ranging between 1.75 m for some setters to more than 1.90 m for many spikers. Suppose we choose at random 100 female volleyball players from the Italian first division. Which group do you think is the most numerous? (Check your choice.)
- Women who are less than 21 years old.
 - Women who are less than 21 years old and are taller than 1.77 m.
 - Women who are less than 21 years old and are not taller than 1.77 m.

Notice that the word “probable” does not occur in these problems.

The implication questions were identical to (12) and (13) except that plural sentences were used; this ensured grammatical equivalence with (14) and (15). We illustrate with the new version of (12).

- (16) IMPLICATION QUESTION FOR THE SCANDINAVIA PROBLEM, FREQUENCY FORMAT: Luke is in his last year of high school. One morning he met Mika and Tarja, new students from Finland. Mika and Tarja have blond hair and blue eyes. Speaking together, Luca learned that Mika and Tarja like to play the piano and are in Italy because their fathers were transferred to the Milan branch of a large foreign bank. At home Luca tells his sister about Mika and Tarja, and makes several claims about them. From among the statements shown below, please indicate which are true, which are false, and which might be either.
- (a) Mika and Tarja were born in Helsinki.
 - (b) Mika and Tarja hate to play the piano.
 - (c) Mika and Tarja have blue eyes.
 - (d) Mika and Tarja like living in Milan.
 - (e) Mika and Tarja have blond hair.
 - (f) Mika and Tarja say that their families move often because of their fathers’ work.

Items (c) and (e) allow test of the claim that $X\text{-and-}Y \models X, Y$.

3.3. Results

Forty-six of the 50 participants responded with *True* to both crucial items in both implication questions thereby showing agreement with the implications in (7). Of these 46 students, 26 failed in both the Scandinavia and Volleyball problems [(14) and (15)] to choose the X option as most probable; 35 of the 46 students failed to choose X in at least one of the two problems. The percentage of choices for X , $X\text{-and-}Y$, and $X\text{-and-not-}Y$ are shown in Table 1. As in Experiment I, the $X\text{-and-}Y$ alternative was chosen most. The hypothesis that $X\text{-and-}Y$ had a one-third chance

of selection in the Scandinavia problem, frequency format, was rejected by a binomial test ($p < .05$); the same hypothesis was also rejected in the Volleyball problem ($p < .001$).

The results of Experiment II confirm those of Experiment I. The slight decrease in fallacious responding with frequency formats is not statistically significant.

4. Discussion

Both experiments reveal numerous judgments of form $\text{Prob}(X\text{-and-}Y) > \text{Prob}(X)$. Such judgments are fallacious if participants endorse the implication $X\text{-and-}Y \models X$, which our results strongly suggest. The fallacy cannot be explained by the ambiguity of the word “probable” (Hertwig & Gigerenzer, 1999) since Experiment II avoided such terminology altogether. It also appears unlikely that the fallacy results from interpreting X as $X\text{-and-not-}Y$ (e.g., Dulany & Hilton, 1991) since $X\text{-and-not-}Y$ was given explicitly as an alternative.

Nor does it disarm the fallacy to claim that many people evaluate $\text{Prob}(X\text{-and-}Y)$ via the conditional probability of Y given X (see Fisk, 1996; Hertwig & Chase, 1998, and references cited there). Even if this claim is true, it merely indicates the reasoner’s path to fallacy. Such use of conditional probability is compatible with assigning $X\text{-and-}Y$ a higher probability than the one assigned to Y , so conditional probability should not be used in this way by anyone wishing to conform to the probability calculus. Perhaps it will therefore be agreed that these data point to a genuine (and elementary) error in reasoning about chance.

Speculation about the causes of the conjunction fallacy is offered in many places (e.g., Fisk, 1996; Hertwig & Chase, 1998; Shafer, Smith, & Osherson, 1990; Sides et al., 2002; Tversky & Kahneman, 1983). Here we observe only that the fallacy appears to involve failure to coordinate the logical structure of events with first impressions about chance. Understanding the reasons for this failure might illuminate fundamental properties of the human cognitive system.

Notes

1. The exact rendition of $X\text{-and-}Y$ was: “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.” It was explained to subjects that the truth of each sentence was to be evaluated in terms of the specific date indicated.
2. Similar results are presented in Bar-Hillel and Neter’s (1993) study of violations of the disjunction law (according to which the probability of a given event cannot be higher than the probability of any event that includes it). Tversky and Kahneman (1983) also report a betting experiment. Alternative interpretations of “probability” locutions include non-additive support (Shafer & Tversky, 1985), Baconian evidence (Cohen, 1989; Perez-Ramos, 1988), and various measures of confirmation (Fitelson, 1999).
3. From (7c) and (8) we infer $\text{Prob}(X \wedge Y) \geq \text{Prob}(X\text{-and-}Y)$. By (2), $\text{Prob}(X\text{-and-}Y) > \text{Prob}(Y)$ which yields $\text{Prob}(X \wedge Y) > \text{Prob}(Y)$ via the transitivity of $>$.
4. The Italian text is available via <http://www.discof.unitn.it/laboratori/CRD/cf/index.html>.

5. The personal interpretation of the term “probable,” moreover, appears to be deeply rooted in ordinary discourse. For a survey of usage through history, see Bellhouse and Franklin (1997).
6. However, the impact of frequency formats appears to interact with other variables such as the prior probability of component categories (Mellers, Hertwig, & Kahneman, 2001), the transparency of the logical relation between conjunction and conjunct (Kahneman & Tversky, 1996; Mellers et al., 2001; Sloman, Over, Slovic, & Stibel, 2003), the experimental design (Kahneman & Tversky, 1996), and the response mode (Sloman et al., 2003). Fiedler (1988) and Hertwig and Gigerenzer (1999) interpret frequency effects in terms of a predisposition for comprehending frequencies. In contrast, Kahneman and Tversky (1996) as well as Sloman et al. (2003) interpret the effect as a consequence of the extensional cues that frequency formats make salient.

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