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Abstract

This study aimsto explain theconjunction fallacy (Tversky&Kahneman, 1983) in terms of degree of confirmation (Crupi, Tentori, & Gonzalez,2007) by employing corpus data analysis. To accomplish this, wecalculated indexes of the degrees of confirmation fromthe British National Corpus and fitted them to dataof the previous study (Shafir et al., 1990). The resultsshow that a major index of the degree of confirmation(Crupi et al., 2007) can significantly predict theconjunction fallacy, indicating a relationship betweenthe conjunction fallacy and degree of confirmationas well asthe importance of corpus data to explain biasesin judgment.

Keywords: Conjunction Fallacy, Degree of Confirmation, Corpus Data Analysis

Introduction

The conjunction fallacy (Tversky&Kahneman, 1983) is one of the most famous violations of the normative axiom of probability. A representative experiment of this phenomenon asked participants to think about Linda as she is described in the following sentences:

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

Then, participants were required to rank various statements about Linda "by their probability." Two of thesestatements were"B" and "B and F":

(B) Linda is a bank teller.

(B and F) Linda is a bank teller and is active in the feministmovement.

In Tversky and Kahneman (1983), 85% of the participants ranked"B and F" as more probable than "B." This judgment is in apparent violationof the conjunction law $Pr(X \text{ and } Y|Z) < Pr(X|Z)$ forany statements X, Y, and Z, with strict inequality for nontrivialcases such as the present example.Tversky and Kahneman refer to this violation as the conjunction fallacy, and many studies have replicatedit under various experimental conditions (see Hertwig&Chase,1998, for a review of findings; the original report is Tversky&Kahneman, 1983).

Many theoretical explanations for the conjunction fallacy as well as the replications have been reported (for a review, see Costello, 2009; Sides, Osherson, Bonini, &Viale, 2002). Some researchers (e.g., Crupi, Fitelson, &Tentori, 2008; Tversky&Kahneman, 1983) suggest that participants' responses in the conjunction fallacy are not based solely on the probability of the conjunction itself but also on other factors such as the representative heuristics (Tversky&Kahneman, 1981) or degree of the confirmation given by the conjunctions. Other researchers assume that participants utilize their pragmatic knowledge to understand meanings of the experimental materials employed in studies on the conjunction fallacy. This approach focuseson assumptions about how participants answer in the experimental tasks (Chase, Hertwig, &Gigerenzer, 1998; Dulany& Hilton,1991; Macdonald &Gilhooly, 1986; Morier&Borgida, 1984; Politzer&Noveck, 1991), saying that participants, correctly following the pragmatics of communication rather than the logical meaning in the experimental task, interpret the single statement B asmeaning "B^notA" and so rightly prefer the conjunction B^A (Dulany& Hilton, 1991; MacDonald &Gilhooly, 1990; Politzer&Noveck, 1991). In addition, researchers have recently proposed that the conjunction fallacy is an artifact that occursdue to unnatural experimental settings (Hertwig&Gigerenzer, 2002),possibly incombination with measurement error (Costello, 2008).

We seek to propose another explanation of the conjunction fallacy that is inspired by a recent development of the concept of confirmation (Carnap, 1955; Fitelson, 1999; Crupi, Tentori, & Gonzalez, 2007) and utilizes statistical corpus analysis. In what follows, we will argue how theories of confirmation can explain the conjunction fallacy. In addition, we will also present a solution to these problemsusingstatistical corpus analysis.

Degree of confirmation

Consider a situation in whicha rational agent collects data for hypothesis confirmation. The strength of the agent's belief about the hypothesis after seeing the data can be described as the posterior probability of the hypothesis, defined by Bayes' theorem, shown in (1):

$$P(h \mid d) = \frac{P(h)P(d \mid h)}{P(d)} \qquad (1)$$

As you can see, Bayes' theorem defines a relationship between the prior belief ($P(h)$) and the posterior belief. In this vein, *whether* the data support the hypothesis or not can be represented by the difference between the prior and posterior probabilities; when the posterior probability is higher than the prior probability, the data support the hypothesis, and when not, they disconfirmit. Thus, degree of confirmation $c(h, d)$ can be expressed as shown in (2):

$$c(h,d) \begin{cases} > 0, P(h \mid d) > P(h) \\ = 0, P(h \mid d) = P(h) \\ < 0, P(h \mid d) < P(h) \end{cases} \qquad (2)$$

We must mention that it is possible to define many kinds of criteria that can satisfy the equation in (2).This equation solely proposes that the data support the hypothesis if the posterior probability is higher than the prior probability;it does not determine the degree of support. In fact, there are various types of criteria for degree of confirmation that can satisfy (2). Table 2 shows representative indexes of the degrees of confirmation (also see Eells&Fitelson, 2002; Fitelson, 1999; Tentori, Crupi, Bonini, &Fitelson, 2007).

Tentori, Crupi, Bonini, and Fitelson (2007) report on experiments that compared the adequacy of several such measures as descriptions of confirmation judgmentin a probabilistic context. In the experiments, they showed participants two opaque urns that contained different numbers of white and black balls, and the numbers of each were known to the participants. Then, participants randomly chose one of the two urns by a coin toss, but the outcome of the coin toss was unknown to them. After selecting an urn in this way, the participants were required to draw a ball and estimate the impact of the results of the ball drawing with various types of response scales in 10 successive trials. Based on the number of balls that the two urns contained, theparticipants calculated various types of the confirmation indexes and compared them to the estimated degree of confirmation. Results showed that some of the confirmation indexes significantly correlate to the participants' responses, indicating that human hypothesis confirmation follows rational thought as the Bayesian agent is assumed to do so.

Crupi, Fitelson, and Tentori (2008) suggest that the conjunction fallacy can be explained in terms of the Bayesian hypothesis confirmation. They insist that participants in the conjunction fallacy experiments do not consider probabilities for conjunctions or each proposition that composes the conjunction. Rather, they appear to estimate how the description supports the conjunction as data. Based on this idea, Crupi, Fitelson, and Tentori specify a condition in which the degree of confirmation for the conjunction becomes larger than that for each proposition. This condition is shown in (3):

$$c(h_1, e) \lessgtr 0 \quad and \quad c(h_2, e \mid h1) \gtrless 1,$$
$$then \ c(h_1 \& h_2 \mid e) \gtrless c(h_1, e) \qquad (3)$$

Another important feature of the condition is its robustness; Crupi et al. (2008) also show that this condition holds any confirmation measures, including *D*, *R*, *L*, *C*, *S*, and *Z* (table 1). In other words, each of these confirmation measures can explain the conjunction fallacy if people's probability judgment about conjunction depends on the degree of confirmation. Thus, not only *whether* the degree of confirmation but also *what* measure can explain the conjunction fallacy is an interesting empirical question.

Table 1.variation of the degree of conformation

$$D(A,E) = p(A \mid E) - p(A)$$

(Carnap, 1950; Eells, 1982)

$$C(A,E) = p(A \& E) - p(A) \times p(E)$$

(Carnap, 1950)

$$S(A,E) = p(A \mid E) - p(A \mid \neg E)$$

(Christensen, 1999; Joyce, 1999)

$$Z(A,E) = \begin{cases} \dfrac{p(A \mid E) - p(A)}{1 - p(A)} & \text{if } p(A \mid E) \geq p(A) \\ \dfrac{p(A \mid E) - p(A)}{p(A)} & \text{otherwise} \end{cases}$$

(Crupi, Tentori& Gonzalez, 2007)

However, one methodological problem of Crupi et al.'s (2007) explanation lies in how to determine probabilities related to the conjunction. All the confirmation measures, although they are not probabilities themselves, require values of probabilities for h_1, h_2, and *e*. In the experimental paradigm of the conjunction fallacy, this requirement is very difficult to fill, because the conjunction fallacy demonstrates that peoples' probability judgments for these components deviate from the normative principle. In other words, we cannot define the values of the probabilities required to calculate the degree of confirmation from probability judgment data. Rather, it is desirable to define the probability values based on objective data, not on subjective probability judgments.

Statistical corpus analysis

Statistical corpus analysis can address the above problems. Statistical corpora containlarge amounts of sentences that are collected from natural language communication such as literature (British National Corpus) or newspapers (Mainichi-shinbun database) and enableresearchers to access information on word frequencies or co-occurrences.

These databases can be considered as reflecting everyday verbal communication and have assumed to be substitutionsfor human memory structure (e.g., Steyvers&Tenenbaum, 2006; Stewart, Chater, & Brown, 2006).

Recently, the number of studiesthatattempt to describe human reasoning with corpus statistical data has been increasing (e.g., Sakamoto & Nakagawa, 2007; Stewart, Chater, & Brown, 2006; Terai & Nakagawa, 2007; Utsumi, 2010).These studies assume that frequencies of appearance or co-occurrence among words reflect word affinities or the strength of associative connections among words and substitutethem as parameters for statistical models. For example, Sakamoto and Nakagawa (2007) hypothesized cognitive processes of category-based induction (e.g., Osherson et al., 1990) as classification based on associations between premises and conclusions, and employed probabilities for co-occurrence among the words that are contained in the premise and conclusion. The results of their study supported the hypothesis, suggesting that probabilistic properties of corpus data reflect basic knowledge of human reasoning.

Additionally, applying the corpus data analysis approach to the issue of the conjunction fallacy appears to be very natural upon inspection oftheexperimental procedure. In the typical experiment, participants read sentences that describe features of characters, such as "outspoken" or "philosophical," and are required to rank alternatives (e.g., "bank teller,""feminist") by their probability. In this situation, it is natural to assume that participants access their memory to solve the task and that this assessment to their memory affects their probability judgment foreach proposition. If corpus data reflect memory strength of the words contained in the stimulus sentences, we can employ the corpus data to test Crupi et al.'s (2007) hypothesis.

The purpose of this study

From the above discussion, we derive the following hypothesis about the conjunction fallacy; in the experimental procedure of the conjunction fallacy,participants estimate the degree of confirmation for the conjunction by assessing their memory strength. To test this hypothesis, we report two studies. The first reanalyzed the data of Shafir, Smith, and Osherson (1990) that are adequate to test our approach. The second collected new data from Japanese participants. In both studies, we calculate parameters of the degrees of probability with any given assumptionusinga language corpus and examine the idea that the conjunction fallacy occurs as a result of the Bayesian updating of degree of the confirmation.

Study 1: Reanalysis of Shafir et al. (1990)

The purpose of Study 1 is to test our hypothesis by reanalyzing the data of Shafir et al (1990). Shafir et al (1990) required participants to rate probabilities of occurrence of the contents of both 15 conditional sentences and combinations of propositions. The sentences that were judged by participants had the frame: Every single in the group is . For example, they employed stimulus sentences such as those below in order to considerthe conjunction fallacy by comparing single and conjunctive condition texts:

Single condition:
　"Every single lawyer in the group is conservative."

Conjunctive condition:
　"Every single labor-union lawyer in the group is conservative."

In this case, the data (e) is "conservative" and single hypothesis ($h1$) and conjunctive hypothesis ($h1\&h2$) are "lawyer" and "labor-union lawyer," respectively. The participants were request to rate the probability of each conditions.They calculated the degree of fallacy by subtracting the probability of the single condition from the probability of the conjunctive condition.

In Shafir et al.'s (1990) experiment, the attributes of the data (e) and hypothesis (h1, h2) are comprised of one word. In such experiments on the conjunction fallacy using stimuli, it is natural to assume that participants' judgments are dependent on the characteristics and relationships of each word; therefore, it is very appropriate to consider the connection of language statistics and the conjunction fallacy. Thus, we selected it as the subject of analysis of this study. This study compares the degree of conformation that was calculatedform the occurrence and co-occurrence probabilities of words in a language corpus and the results of the conjunction fallacy experiment performed by Shafir et al. (1990).

We use the British National Corpus (BNC) as language statistical data. The BNC, launched in 1991, is the world's largest English corpus, consisting of approximately 100 million words including both British written and colloquial words, and is designed to represent modern British English as broadly as possible. It consists of approximately 90% written words and 10% colloquial words. Data to be added are selected based on statistical value by area of the number of annual publications in the UK. We decided to usethe BNC as the original data source for calculating the degree of probability for the study because it contains enough data, and the date on which the original BNC texts were prepared is close to, or prior to, the date Shafir et al.'s (1990) experiment was performed.
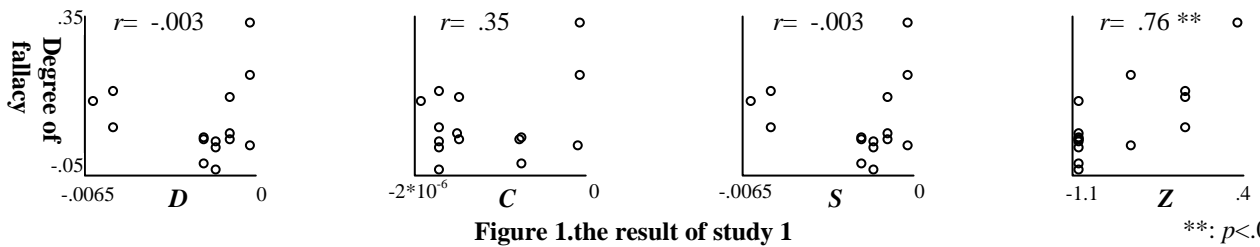
Figure 1.the result of study 1

**: $p < .01$

The degree of probability was calculated through the following procedure.

First, we calculated occurrence and co-occurrence probabilities. We picked up 5,101,034 sentences by BNC. A frequency of a word (e.g. *h1*) was counted according to whether the word (*h1*) is included in each sentence. The occurrence probability of h1 was calculated as follows,

$$p(h1) = n_{h1}/n_{all}$$

where the n_{all} is a number of all sentences ($n_{all} = 5,101,034$), and the n_{h1} is the frequency of the word (*h1*) .

In the case of co-occurrence (e.g. *h1&h2*), we counted a co-frequency according to whether both words (h1) and (h2) are included in each sentence. The co-occurrence probability p(h1 & h2) was calculated as follows,

$$p(h1 \& h2) = n_{h1 \& h2}/n_{all}$$

where the $n_{h1 \& h2}$ is the co-frequency of words (h1 & h2).According to the above procedure, all occurrence and co-occurrence probabilities for calculation of the confirmation-degree are calculated.

Then, after the calculating conditional probability based on Bayes' theorem, we calculated the degree of confirmation (*c(h1,e), and c(h1&h2,e)* for each confirmation measures)to determine the degrees of probability of the conjunction and each proposition. Finally, we calculated the correlation coefficient between the degree of fallacy of Shafir et al. (1990) and *c(h1&h2,e)-c(h1,e)*.

Scatter plots in Figure 1 demonstrate relationships among the data of Shafir et al. (1990) and values of the confirmation measures that are calculated from the BNC. Among the four confirmation measures, only *Z* correlated to the data significantly (*r*= 0.76, *p*< 01). These results support our proposition that the degree of confirmation calculated from the corpus data can explain the conjunction fallacy. Of course, robustness of the current results should be examined by another study, and Study 2 attempts to replicate this finding by using Japanese corpus in Japanese participants

Study 2 Examination in Japanese participants

In study 2, we conductedanexperimentby using Japanese corpus for Japanese participants. The participants were 77 Japanesecollege students in a computer-literacy class.In the experiment, we used same contents that used in Study 1and translated those 15 conditional sentences and combinations of propositions in Japanese.Participants were given the personality character and required to select one statement as most probable.

For example, participants were asked to think about a person Awho is described in the following sentences:

"A is conservative. "

Then, participants were required to select one statement from three statements as most probable about person A. Three of these statements were as follows,

   i. A is lawyer.
   ii. A is labor unionist.
   iii. A is labor-unionist and lawyer.

In this case, the data (*e*) is "conservative," and two single hypothesis (*h1, h2*) and conjunctive hypothesis (*h1&h2*) are "lawyer", "labor unionist" and "labor-unionist and lawyer," respectively. In study2, a degree of fallacy is defined by selected ratio of conjunctive statement (iii).

In study2, we use a Japanese corpus data that consists of approximately 650 million words, which extracted from 18-yearsspan of a Japanese news paper (Mainichi Shinbun), 9706 books (by Aozora Bunko), two encyclopedias (Gakken KokugoDaijiten, Nihon HyakkaJiten) and Blog data. This Japanese corpus data consists of approximately 67% news papers, 8% books, 15% blogs and 10% encyclopedias. The degree of confirmation (*c(h1,e), c(h2,e)* and *c(h1&h2,e)* for each confirmation measures) was calculated through the same procedure in Study 1. We calculated the correlation coefficient between *c(h1&h2,e) – c(h1,e)* (or *c(h1&h2,e) – c(h2,e)*) and the degree of fallacy of the result of experiment.

Figure. 2 show the relationshipsamong the data of experimental result and values of the confirmation measures that are calculated from Japanese corpus. In the case of the*c(h1&h2,e) – c(h1,e)*, *Z* correlated to the data significantly (*r*= 0.64, *p*< .05) , and the relation between *c(h1&h2,e) – c(h2,e)* and the degree of fallacy shows marginal significant positive correlations in the degree of *Z* (*r*= .46, *p*< .1).
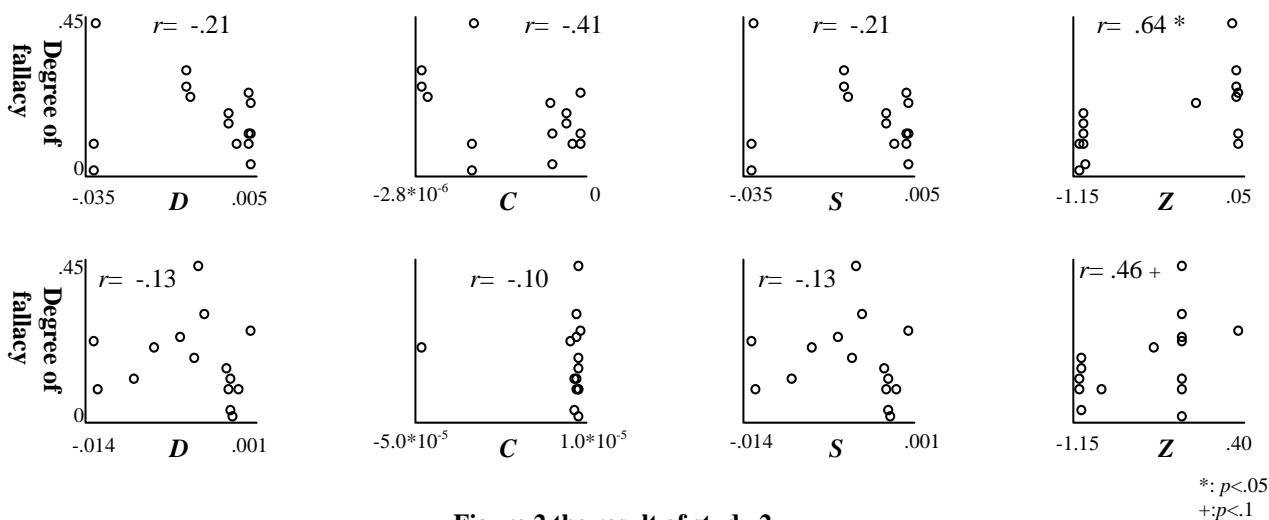
Figure 2.the result of study 2
Upperside : the relationship between c(h1&h2,e)-c(h1,e) and the degree of fallacy.
Bottom side : the relationship between c(h1&h2,e)-c(h2,e) and the degree of fallacy

Discussion

The results of the two studies consistently showed that conjunction fallacy is explained by the degree of confirmation that can be defined by difference between prior and posterior probability that are reflected in the corpus data. These results are consistent with the hypotheses by Crupi et al. (2007), and can be positioned as another example that succeeded to explore cognitive processes of human reasoning by utilizing the corpus data.

We argue that the corpus data analysis is prospective approach to explore biases in human reasoning. Although the corpus data have been used to explore human reasoning such as category-based induction (Sakamoto & Nakagawa, 2007) or metaphor understanding (Terai & Nakagawa, 2007), application to the domain of cognitive biases very novel. We think that probabilistic aspects of the corpus data are useful for investigation to various agendas of decision-making research. We are planning to perform similar analyses and experiments on such decision making agendas to assess the probability of prediction of human decision-making through calculation of degree of probability based on language corpus.

Among the various types of the criteria of degree of confirmation, *Z* showed the highest fit to the data. This finding is meaningful because it suggests general cognitive processes for probability judgment including the conjunction fallacy. As the expression show in Table 2 indicates, this index defines degree of the confirmation as normalized difference between prior and posterior probability: when the targethypothesis is supported, sum of prior probabilities for hypothesis other than the target hypothesis becomes a normalizing term, and when disconfirmed, prior probability of the target hypothesis become the normalizing term. In other words, this index uses set of the disconfirmed hypotheses as the normalizing term. In this vein, this index considers degree of confirmation as a result of competition between the target and the other hypothesis. This finding corresponds to recent findings that consider human reasoning as comparison between the target and alternative hypothesis (e. g., McKenzie & Amin, 2002; McKenzie &Mikkelsen, 2002, 2007). In addition superiority of Z suggests a coherency of human judgment because it satisfies the conditions needed to be a coherent index of confirmation (Crupi et al, 2007). In sum, the current results suggest a possibility that conjunction fallacy can be positioned as result of the rational cognitive processing. Although Costello (2008) made normative sense of the conjunction fallacy considering combination of measurement error terms, the current study proposed another explanation that can also rationalize the conjunction fallacy in terms of the normative sense.

One crucial assumption of this study is that probabilities for statements can be measured from the corpus data. Our rational for this assumption is mainly based on the findings in the previous studies that succeeded to explain human reasoning by utilizing the corpus data (e. g., Sakamoto & Nakagawa, 2007; Stewart, Chater, & Brown, 2006; Terai& Nakagawa, 2007; Utsumi, 2010). This rationale strongly depends on pragmatic arguments: that is, it solely states that this assumption is valid because of its ability to predict the data. Thus, this rationale does not appear to be strong because it does not explain *why* the corpus can be utilized to predict probability judgment. We believe that the current study add another evidence for utility of the usage of corpus data to investigate human reasoning. However, we must clarify our rational more precisely to justify using the corpus data for probability judgment.

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