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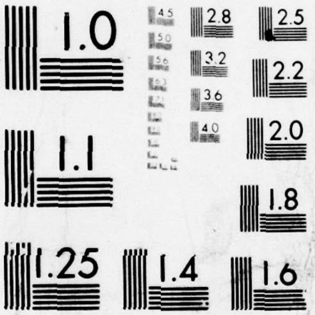

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RESEARCH REPORT

AN EMPIRICAL INVESTIGATION OF BAYESIAN INFERENCE WITH TWO PEOPLE

WILLIAM F. GABRIELLI, JR.
WARD EDWARDS

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DECEMBER 1978

SSRI RESEARCH REPORT 78-8

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An Empirical Investigation of
Bayesian Inference with Two People

Research Report 78-8
December, 1978

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University of Southern California

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Summary

Twenty subjects from the University of Southern California performed a Bayesian inference task in pairs. Like earlier research in inference, the individuals were asked to infer posterior odds about a pair of hypotheses from a collection of data. Unlike the earlier studies, the individuals were then required to aggregate their posterior odds with those of another individual who had seen a second set of independent data samples to form an opinion about the same pair of hypotheses.

Conservatism and radicalism findings of earlier studies were reconfirmed. Individual subjects' responses collected before aggregation showed conservatism in the high d' condition and radicalism in the low d' condition.

The aggregated final odds from the pairs of subjects seem to reflect some confusion. Some of the subjects apparently used a simple and incorrect averaging strategy. Others did not use this strategy, but in general, pairs of subjects were unable to provide anything but conservative final odds when they aggregated their two opinions.

The importance of using real stimuli, the way the responses were elicited, and the instructions that were given to the subjects are discussed. Also, a "mean of means" or arithmetic log likelihood response mode is discussed as an alternative elicitation mode that may be useful in information aggregation when more than one person is involved

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ACKNOWLEDGEMENTS

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DISCLAIMER

INTRODUCTION

The study reported here extends Bayesian inference to the case in which two people rather than one must interpret information and reach a group conclusion. Each of the two people has conditionally independent information relevant to which of the competing hypotheses is true. The information of one subject is different from that of the other subject, and even the combination of data available to both cannot provide certainty. One of the two subjects has more diagnostic information than the other. No conflict exists over what is known. The two must combine their information to make a joint inference about the probabilities of the two hypotheses.

Studies of inference in the one person case have been summarized in Edwards (1968), Anderson (1971) and Slovic and Lichtenstein (1971). Generally, people are conservative as individuals in their judgments. They fail to combine the information to modify prior probabilities as strongly as the data would justify (Wheeler and Edwards, 1975).

Eils, Seaver and Edwards (1977) showed that subjects avoid conservatism if asked to assess an average impact of information, rather than cumulating information over successive data. A cumulative response requires a response number outside the range of the inputs, while an average requires a response somewhere in the middle of that range. Apparently, averaging is far easier than cumulating.

This experiment explores a kind of information aggregation problem for which cumulating is essential. It provides one set of data to one subject and another set, of different diagnosticity, to another subject, and then requires a joint assessment of certainty based on both sets of data. No averaging response mode that makes easy intuitive sense can be designed for this task.

I. FORMAL RULES

Bayes Theorem, the formula for calculating the exact probability of one hypothesis as compared with another given n data and a prior odds, is:

$$\Omega_n = \Omega_o \prod_{i=1}^{n} L_i \qquad (1)$$

where Ω_o is the prior odds in favor of the hypothesis A over its alternative hypothesis not A. L_i is the likelihood ratio for the ith datum, and Ω_n the revised posterior odds.

With log transformation, this formula becomes:

$$\mathrm{Log}\ \Omega_n = \log \Omega_o + \sum_{n=1}^{n} \log L_i \qquad (2)$$

If the subjects are able to provide arithmetic mean log likelihood ratios (AMLL), the posterior odds will be:

$$\Omega_n = \Omega_o 10^{n(\mathrm{AMLL})} \qquad (3)$$

where

$$\mathrm{AMLL} = (1/n) \sum_{i=1}^{n} \log L_i \qquad (4)$$

Here, the final posterior odds ratio is calculated after the subject gives his AMLL estimates.

When each of two people have independent information relevant to a comparison between two hypotheses, the aggregation of that information should be similar to the case in which the same person has two pieces of independent information. If the two people express their feelings based on their own information in likelihood ratios, then they should combine that information using Equation (1), assuming that the information available to each is conditionally independent of that available to the other. If their assessments are expressed as posterior odds (or some quantity from which posterior odds can be infered), the arithmetic is slightly more complicated. First, a prior odds or log prior odds must be known for each; in experiments, this is usually supplied in instructions. Then, either the aggregate likelihood ratio, its logarithm, or the AMLL should be recovered separately for each, using Equation 1, 2, or 3 as appropriate.

Finally, the two assessments should be combined. One way to do so would be to perform the appropriate aggregation for one subject and then use his posterior odds as the prior odds for the other subject. (Since the two subjects receive independent information, this can be done in either order.) Another way is to use Equation 1 or 2 or 3, as appropriate, to obtain an aggregate likelihood ratio for each subject, representing the total aggregate impact of the data that the subject has seen.(Note that his aggregate cannot be an AMLL; it must be a cumulative rather than a mean quantity.) Then the two measures of aggregate impact for the two subjects can be combined, by adding them together if they are in logarithmetic form or by multiplying them together if they are in non-log form. Finally, the output of this combination process across subjects can be combined with the original prior odds.

II. METHODS

Subjects

Twenty undergraduate psychology students at the University of Southern California voluntarily participated as subjects.

All of the subjects received generous participation credit in their introductory psychology class.

Procedure

Subjects participated in pairs. The experimenter told each pair that he had prepared samples from two book bags, each filled with 1,000 poker chips. One of the two book bags contained a majority of blue chips while the other was predominately red. Each subject, working alone, then worked through a response booklet. The first page explained the task. Each subsequent page presented a sample (with replacement) from a book bag; the subjects understood that each successive sample represented a new selection of which bag was being sampled. Every such selection of a bag resulted from a flip of a fair coin.

One of the two subjects in each pair had samples drawn from book bags that had either 750 red chips and 250 blue ones or 250 red chips and 750 blue ones. These data were relatively highly diagnostic; d' = 1.15. The book bags from which the other person's samples were drawn had a 600 to 400 ratio of red chips to blue ones or the reverse. This person's samples were, therefore, relatively less diagnostic given the same number of chips and sample composition (d' = .41). Subjects were informed of the ratio (750:250 or 600:400) from which their samples came. The actual samples the individuals saw are reprinted in Table 1.

The likelihood ratios in Table 1 are easier to verify if one exploits a useful property of symmetric binomial examples like this one. (Symmetric binomial simply means that the two hypotheses are equidistant from 0.5 in opposite directions.) In such cases only, the likelihood ratio for any set of observations is given by the equation

$$L = \left(p/q \right)^{(s - f)} \qquad (5)$$

The symbols p and q refer to the probability of the more and of the less common chip in the sample, respectively. So p/q = 3 for the high diagnosticity bag and 1.5 for the low diagnosticity bag. The symbols s and f stand for successes and failures (time-honored terms from statistical applications of binominal arithmetic);

Table 1. Actual 20 Samples for the 10 Pairs of Subjects

Sample	High Diagnosticity	True Likelihood Ratio	Low Diagnosticity	True Likelihood Ratio
1	BRBR	1.00 (N)	BBBR	3.375 (B)
2	RRBRB	3.00 (R)	RBRRRRRR	11.39 (R)
3	RBBRBBBB	81.00 (B)	BRRBB	1.50 (B)
4	RRBRR	27.00 (R)	RRBB	1.00 (N)
5	RRRRR	243.00 (R)	BRBRRRR	3.375 (R)
6	RRRR	81.00 (R)	RRBRRB	2.25 (R)
7	RRRB	9.00 (R)	BBRR	1.00 (N)
8	BRBRBBB	27.00 (B)	BBBBB	7.59 (B)
9	RBBRRR	9.00 (R)	RRBRRB	2.25 (R)
10	BRBRR	3.00 (R)	RBRB	1.00 (N)
11	RBRRB	3.00 (B)	RRRBBB	1.00 (N)
12	BBBBRBBB	729.00 (B)	RBRBRBB	1.50 (B)
13	BRBRRB	1.00 (N)	RRRR	5.06 (R)
14	RRRBRRBR	81.00 (R)	RRRRBBRR	5.06 (R)
15	BRRBR	3.00 (R)	RBBBBRRR	1.00 (N)
16	RRRR	81.00 (R)	BBBRRB	2.25 (B)
17	BBBBBB	729.00 (B)	RRBBRBB	1.50 (B)
18	BBRBB	27.00 (B)	BRBRB	1.50 (B)
19	RBBRB	3.00 (B)	RBRRRR	5.06 (R)
20	BRRRRBRR	81.00 (R)	RRBRBBRR	2.25 (R)

Note: The symbol R means that a Red chip was drawn; B means that a Blue chip was drawn. Order is irrelevant. The high diagnosticity samples come from the 750-250 bag; the low diagnosticity samples come from the 600-400 bag. (R) following a likelihood ratio means that it favors the predominantly Red bag; (B) means that it favors the predominantly Blue bag, and (N) means that the sample is neutral, i.e. it contains equal numbers of chips of each color.

in this instance, a success is an occurrence of the event more common in the sample, while a failure is an occurrence of the less common event in the sample. Obviously a sample with more reds than blues favors the predominantly red bag and a sample with more blues than reds favors the predominantly blue bag.

After each subject individually had recorded his responses to all 20 samples, the two subjects in each pair were brought together. The experimenter explained that each sample shown to one subject corresponded to the same numbered sample shown to the other subjects, in the sense that both had come from book bags having the same predominant color.

This information, given to ideal Bayesians, would imply that they could combine the information in each pair of samples just by multiplying the two likelihood ratios together. The resulting product, multiplied by the prior odds, would yield an appropriate joint posterior odds.

For example, if a subject judged that sample number two was twice as likely to have come from the predominantly red bag, as from the predominantly blue bag, and his partner judged a likelihood ratio in favor of the same bag of 25:1, the group likelihood ratio should have been 50:1 in favor of that hypothesis, just as if only one individual had obtained both pieces of information.

The experimenter then seated both subjects at a table, each with his previously filled in response booklet in front of him. Yet another response booklet was provided, and the experimenter asked the pair to reach an agreed-on assessment of the probability that the predominant color of the book bags represented by the pair of samples was (say) red. In arriving at this agreed-on assessment, neither subject was permitted to report the sample he had based his judgments on to the other subject. But they were permitted to report their assessments of likelihood ratios based on each sample. They were instructed to consider the two samples conditionally independent, and to consider their individually assessed likelihood ratios as correct, for the purpose of reaching a group assessment.

III. RESULTS

Four different sets of numbers can be compared with one another for each pair of subjects and each sample. They are:

A. Individual responses to each sample.

B. The group's actual response to each sample.

C. A number calculated by multiplying together the likelihood ratios estimated by each of the two members of the group for the particular sample.

D. A correct Bayesian solution, obtained by using Bayes's Theorem for each sample. In the individual response comparisons, this produces the appropriate likelihood ratio. In the group comparisons, it is also necessary to multiply together the likelihood ratios thus obtained for each member of a pair.

These numbers were compared with one another via regression analyses, keeping individual subjects or pairs of subjects distinct but aggregating over samples. As might be expected of untrained subjects, performing an abstract task with little motivation to do it carefully, the data are highly variable. Nevertheless, certain patterns emerge from them that can be most easily displayed by looking at medians of various kinds. Table 2 represents such medians, spelling out which set of numbers specified above is being correlated with or regressed on what other set.

TABLE 2. Median Correlations & Regressions

Variables being related	r	r^2	Intercept	Slope
Individual responses and correct Bayesian solution, high diagnosticity subjects only (A with D)	.59	.35	.69	.31
Individual responses and correct Bayesian solution, low diagnosticity subjects only (A with D)	.76	.58	.21	1.49
Actual group responses and products of individually estimated likelihood ratios (B with C)	.79	.61	.16	.45
Actual group responses and correct Bayesian solution (B with D)	.54	.29	.48	.23
Products of individually estimated likelihood ratios and correct Bayesian solution (C with D)	.53	.28	.79	.50

Note: In calculating regressions, the first quantity listed is the predicted variable and the second is the x-axis variable. All calculations are based on the logs of the specified quantities, expressed as numbers

The median correlations show modest to medium relations between the variables, as is to be expected from highly variable data. (Note that they would have been much higher if they had not been folded at 0.) The slopes for individual responses show a familiar pattern, standard for virtually every experiment of this kind that has ever been performed. For high diagnosticity data, the subjects were conservative (regression slope less than 1). For low diagnosticity data, the subjects were excessive. Other examples of the same finding include Edwards (1968), and Wheeler and Edwards (1975).

The fact that actual group responses correlate fairly highly with products of individually estimated likelihood ratios means no more than that the two members of each group were allowed to tell each other what their individual estimates had been, and were instructed to take those estimates as veridical for the purpose of arriving at group assessments. But the low slope shows that they did not arrive at these final assessments by the normatively appropriate procedure. Direct observation showed that some pairs, but not all, arrived at final estimates by simply averaging their individual estimates--an easy, incorrect approach. To check how effective a theory simple averaging might be for explaining the group assessments, we also calculated regressions between actual group responses (y) and the mean of the logs, rather than the sum of the logs, of the individual responses (x). The median slope for that regression is .89. Similarly, we calculated the same regression between actual group responses and correct Bayesian numbers; that median is .47. These regressions are too low to permit the conclusion that subjects systematically averaged their estimates. We are left with the conclusion that the subjects found the task confusing, and adopted ill-specified and confused strategies for determining their responses.

The y-intercepts of the regression lines are interesting numbers. For virtually all individual and group responses, they are positive. This fact, combined with the regression slopes uniformly less than 1, implies that the regression lines cross the normatively correct 45° line. Why? Inspection of the individual scatterplots, while emphasizing the disorderliness of the data, suggest that this is not a statistical artifact resulting from an attempt to fit a straight line to non-linear data as some versions of the response bias theory of conservatism (See Edwards 1968) might suggest.

An interesting point, not previously discussed in the man-vs.-Bayes literature, is that response modes, like data analyses, can be folded or unfolded. A folded response mode, like that used in this study, requires the subject first to specify the favored hypothesis, and thereafter to specify some appropriate number saying how strongly the evidence favors it. An unfolded response mode does not first require commitment to either hypothesis An interesting hypothesis, consistent with the findings of initial overconfidence by Tversky and Kahneman (1974), is that the initial task of specifying the favored hypothesis drives up the assessment of how likely the hypothesis is. Thereafter, revisions of opinion based on new data proceed conservatively. This idea would be easy to test, but has not been tested.

V. CONCLUSIONS

The main function of this experiment was to explore whether subjects could properly aggregate numbers representing individual degrees of certainty in order to obtain a group number representing the result of combining information inside several heads. They could not, with the response modes used in this study. Instead, they attemped to reach some sort of compromise based on their individual responses.

The study reconfirmed old findings concerning the relation between diagnosticity and conservatism: high diagnosticity leads to conservatism, whereas low diagnosticity leads to radicalism.

The variability and generally poor quality of the data show the importance of careful instruction, motivation and feedback, and the desirability of using real stimuli (e.g actual book bags and poker chips) rather than a paper-and-pencil task designed to have the appropriate formal characteristics. This point has also been made before; see Slovic, Lichtenstein and Edwards, 1965.

It would be premature to conclude from these data that subjects cannot aggregate evidence properly. It would depend on the response mode. Eils, Seaver, and Edwards (1977) found that if subjects were asked to estimate arithmetic mean log likelihood ratios (Equation 4) they could do a quite good job of aggregating normally distributed evidence; it is likely that the same holds true for stimuli in symmetric binomial experiments like this one. It is natural to extend that response mode to a situation in which evidence must be aggregated in several heads rather than one. If the subjects in this experiment had been asked to estimate mean log likelihood ratios, then they could have done an excellent job of assessing the mean of a group of their individual means based on multi-chip samples. Simple arithmetic, performed on those means of means, combined with knowledge of the number of data on which each was based, would then give an approximation to an appropriate aggregate likelihood ratio. How good the approximation is depends on how far the data deviate from 1:1 likelihood ratio. Formally, the appropriate calculation would be for each subject separately to multiply his mean log likelihood ratio by the number of observations on which it was based, and then for the pair of subjects to add these products together. The result would be an appropriate aggregate log likelihood ratio; added to the log prior odds, it would produce the correct log posterior odds. If the subjects instead average their mean log likelihood ratios, and either they or the experimenter then multiply this mean of means by the total number of observations that the two subjects together had made, a too-high approximation will result. How much too high it will be depends on how much each individual subject's mean log likelihood ratio differs from 0. The farther away both are, the nearer the approximation will be to the correct number.

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Twenty subjects from the University of Southern California performed a Bayesian inference task in pairs. Like earlier research in inference, the individuals were asked to infer posterior odds about a pair of hypotheses from a collection of data. Unlike the earlier studies, the individuals were then required to aggregate their posterior odds with those of another individual who had seen a second set of independent data samples to form an opinion about the same pair of hypotheses. Conservatism and radicalism

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findings of earlier studies were reconfirmed. Individual subjects responses collected before aggregation showed conservatism in the high d' condition and radicalism in the low d' condition. The aggregated final odds from the pairs of subjects seem to reflect some confusion. Some of the subjects apparently used a simple and incorrect averaging strategy. Others did not use this strategy but in general, pairs of subjects were unable to provide anything but conservative final odds when they aggregated their two opinions. The importance of using real stimuli, the way the responses were elicited, and the instructions that were given to the subjects are discussed. Also, a "mean of means" or arithmetic log likelihood response mode is discussed as an alternative elicitation mode that may be useful in information aggregation when more than one person is involved.