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# Answering Autobiographical Questions: The Impact of Memory and Inference on Surveys

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MUCH OF OUR KNOWLEDGE ABOUT GLOBAL, QUANTITATIVE features of society is based on results from large-scale surveys of individual respondents. We depend on such surveys for measures of unemployment, prevalence of crimes and diseases, costs of illnesses, consumer expenditures, and agricultural production. But despite the importance of these results (and despite the large costs associated with such surveys), researchers have given relatively little attention to the mental processes that take place when people answer survey questions. The nature of these processes ultimately determines the accuracy of the resulting population estimates.

Surveys frequently require respondents to answer questions about quantitative aspects of autobiographical events, such as how often they have done something or how much of something they have bought or consumed. Some examples are excerpted below.

- 1) During the 2-week [reference] period, on the days when you drank liquor, about how many drinks did you have? [Health Interview Survey Supplement (1, p. 175)]
- 2) During the past 12 months, about how many visits did you make to a dentist? [Health Interview Survey Supplement (1, p. 168)]
- 3) How many weeks has [name of family member] been looking for work? [Current Population Survey (2)]

4) When you were growing up, how frequently did your father attend religious services? [General Social Survey (3)]

5) About how much did heat, electricity, and water cost you last year? [Study of Family Economics (4)]

6) What was the usual monthly expense for purchased dinners, other meals and snacks in restaurants, cafeterias, cafes, drive-ins, or other such places? [Asked of those reporting such purchases within the last 3 months in the Consumer Expenditure Survey (5)]

7) During a typical week in your principal job, what percent of working time do you devote to management and administration? [Survey of *Science* and Engineering Graduates (6)]

On the surface these survey questions ask for simple recall of unambiguous, quantitative facts, but they actually require far more complex mental processes. For example, respondents do not usually answer the second question by looking up individual dental visits in memory (7). People forget details associated with particular events and may even combine similar incidents into a single generalized memory (8, 9). Faced with a question like the one about dental visits, a respondent may have to rely on inferences or approximations that operate on fragmented recall.

There are many psychological processes that affect accuracy of responses (10).

Respondents encode and interpret survey questions; they place the questions in the

context of their general knowledge and their knowledge of the survey's subject matter; and they gauge the expectations of the interviewer (11) and the social desirability of their answers (12). The effects of these factors are important problems for survey researchers, but ones that appropriate questionnaire design and interviewing procedure can ameliorate (13-15). We focus in this article on two additional mental activities--retrieval and inference--that respondents employ to answer many questions requiring quantitative answers: When? How long ago? How often? How much? The product of retrieval (what is found in memory) is the basis for inferences that combine the recalled information into a single-valued response.

Research on these problems has both practical and theoretical significance. On one hand, it has the potential for increasing the accuracy of surveys and other important autobiographical reports [for example, in medical histories and in epidemiological studies (16)]. On the other hand, it can deepen our knowledge of basic human information processing. In this article, we first outline current experimental results on retrieval of autobiographical facts and the implications of these results for surveys. We then consider an organizational principle that might underlie some forms of autobiographical recall. Finally, we discuss respondents' inferences and their basis in these individuals' beliefs about their own mental processes.

### **Retrieval from Autobiographical Memory**

Many survey questions seek autobiographical quantities for which respondents can recall partial information, even when they cannot remember enough for a precise answer. It is therefore important to understand the properties of memory for autobiographical facts and their potential influence on surveys.

First, it is clear that people sometimes cannot recall an event, even when they have

numerous cues and when the event itself is readily distinguishable from others (8, 17). For example, a recent study of recall for personal events (17) found that 20% of critical details-- selected at the time of occurrence to be "certainly" remembered if the events were recognized--were irretrievable after 1 year; 60% were irretrievable after 5 years (see function for "critical details" in Fig. 1). Similar very long term forgetting functions have appeared in studies of adult memory for the names of high school classmates (18), subject memory for facts about participation in previous laboratory experiments (19), alumni memory for the streets of a college town (20), and college student memory for the events of a semester (21) and for the names of grade school and high school teachers (22). The precise form of the long-term forgetting function clearly depends on the nature of the queried material (Fig. 1).

There is evidence that repeated attempts to recall can bring to light relevant new material, even after nine retrieval sessions of 1 hour each (23). Although some data suggest that no event entirely disappears from memory (24), the effort required for retrieval can be immense, exceeding the capacity of even the most motivated respondent. A personal interview of an hour or an hour and a half typically includes at least 150 questions, rarely allowing more than a minute for a well-considered answer. Telephone interviewing, which has replaced face-to-face interviewing in all but the most important (and expensive) surveys, implicitly demands responses still more rapidly since both interviewers and respondents are uncomfortable with silence (25).

Some recent experiments suggest that it takes on the order of several seconds for people to retrieve a specific event in response to instructions to recall taking part in some common activity, such as going out for a drink or having a haircut (26). This means

that survey accuracy may decline when too many questions are asked within the limited time period that respondents are willing to devote to a survey. Increasing the amount of time for a response can affect the strategy a respondent uses, as well as the accuracy of the resulting answer (7, 27). One effect of longer questions is to give people more time to recall events, thus producing better responses (28).

Recalling autobiographical events is more difficult if memory contains many similar incidents. Initially distinguishable events can become confused or irretrievable because of interference from later events (8, 17, 29). To take a prominent example, John Dean's testimony before the Watergate committee included a detailed description of his meeting with President Nixon on 21 March 1973. This is the meeting where Dean told Nixon of the "cancer" growing on the presidency. The subsequent discovery of tape recordings made in the Oval Office allowed comparison between Dean's testimony and what actually occurred. The 21 March recording revealed deliberations about blackmail demands from Watergate defendants that Dean, in his testimony, placed 8 days earlier. The gist of the conversation was accurate, but despite the intensive preparation for his Senate appearance and the significance of the 21 March encounter, Dean confused the meetings of 13 March and 21 March (30).

Of course, recall usually improves if a respondent has appropriate cues, although different types of cues vary in effectiveness. A prompt about what happened on a particular occasion, who was involved, or where the event took place improves memory for other aspects of the event (17). The date of an event is generally a poorer cue (17, 31). Cues about the location and social occasion of events have successfully increased accuracy of recall in experimental surveys (14). Some surveys that focus on complex information, such as hospital stays, medical expenses, or

household repair costs, ask respondents (by means of an advance letter) to gather records, review them, and have them available during the interview. Other surveys use recall aids, such as lists of events or products, enabling respondents to use recognition rather than recall as a strategy for reporting their behavior (13). The use of records, however, does not guarantee that reports will be accurate. A study in the Netherlands, for example, found that only 47% of respondents who consulted records gave the correct balance in their savings account, a modest increase over the 31% accuracy rate for respondents who did not examine records (32).

Experiments on autobiographical memory show that people achieve better levels of recall if they are required to begin with the most recent item in a series and work backward than if they must begin at the beginning (22, 33). Left to their own devices, however, people prefer forward recall for some events and backward recall for others (33). Most survey designs pay little attention to respondents' strategies for ordering recall of such series as doctor visits, hospitalizations, crimes, or spells of unemployment.

Finally, emotional or important personal experiences (34, 35) or public occurrences, such as presidential assassinations (36), can produce subjectively vivid "flashbulb" memories of an individual's circumstances at the time of the event. Such occasions are less often the target of survey research than everyday happenings like the ones in the sample questions cited earlier; however, they may serve as useful landmarks for everyday events.

### **Temporal Organization for Personal Facts**

Because personal experience takes place in time, it is natural to think of memory as a continuous record. Current experiments, however, suggest that autobiographical

memory has a more discrete temporal structure that inhibits certain forms of recall and facilitates others. Thus, a person might remember a specific episode--say, a visit to a dentist--as part of an extended temporal-causal unit beginning with a toothache, continuing with an initial appointment, and finishing with the last of a series of dental visits. We refer to these connected groups of events as "autobiographical sequences" (37).

One source of evidence for autobiographical sequences comes from the effects of calendars associated with school or work. These calendars impose a pattern on a person's activities and affect the distribution of memories drawn from an individual year. Figure 2 shows the results from two experiments in which college students at Wellesley College and at the University of Louisville described incidents that they remembered from a stipulated year and then dated these episodes (34, 38). The distribution of memories across the months of the year exhibit scallops with peaks near the beginnings or ends of the school and vacation periods. Although we cannot be sure whether students are correctly recalling more episodes from the end-point months or, instead, are mistakenly displacing memories from other months to the end points, these data indicate that people remember autobiographical events as clustered in time.

Further evidence for autobiographical sequences follows from the way people order incidents while reporting their recollections. Asked to describe events from their summer vacation, they tend to group individual activities--for instance, attending a concert or visiting a museum--within more encompassing sequences, such as a trip to a European city. Indeed, people sometimes recall events from one sequence (say, incidents connected with their summer job) and then backtrack, recalling events from a second sequence (for example, a social

relationship) that occurred at the same time as the first (31).

Autobiographical sequences of this sort provide reference points that are useful for locating other events in time. For example, when people are asked to give the date of a headline event such as the first space shuttle launch or the Three Mile Island accident, they often do so by comparing the event to a more easily dated personal sequence (39, 40). A typical response is that the event in question happened "during the year I spent in Japan" or "while I was living on Blackstone Avenue."

These autobiographical sequences, however, are better temporal reference points for some events than for others. In one experiment (39), college students were timed as they decided, for each of a series of news events (for example, the first space shuttle launch), whether the event occurred during an earlier period (1978-1980) or a later period (1981-1983). These intervals appeared in one of two guises: for half the students, the earlier period was described as "Carter's term of office" and the later period as "Reagan's term of office." For the remaining students, the earlier period was described as "the time you were in high school" and the later period as "the time you were in college." The subjects (college seniors in 1984) were selected so that the two sets of descriptions covered the same time period. The critical events were also of two types: either obviously political happenings such as Francois Mitterrand's election in France or Andrew Young's resignation as U.S. ambassador to the United Nations, or nonpolitical (but public) incidents such as the Three Mile Island accident or the first Mount St. Helens eruption. Figure 3 shows the plot of mean time for correct decisions as a function of whether the periods were described as presidential terms (Carter or Reagan) or autobiographical periods (high school or college). On average, these subjects located political events more quickly within

presidential terms, but located nonpolitical events more quickly within autobiographical periods.

Autobiographical sequences provide one way that people can organize their memories of personal events and of some kinds of public events. Although there may certainly be other forms of recall organization, these sequences can be especially useful to survey researchers since they help counteract deficiencies in respondents' temporal inferences.

### **Inferences in Answering Quantitative Questions**

Quantitative answers to survey questions have conventionally been thought to reflect retrieval alone: According to this idea, when respondents have to answer a question such as "How many times did you see a dentist in the last year?" they simply retrieve relevant incidents and count them. Two types of error could occur (41): omission (due to forgotten events) or commission (mostly due to reporting events that actually occurred outside the reference period specified in the question). This is, however, an incomplete description of the mental processes people use to produce a response. In a recent telephone survey that asked how many times the respondent had eaten at a restaurant within the last 2 months, only a quarter of the sample reported using a recall-and-count procedure; when the reference period was extended to 6 months in a new random sample, the proportion fell to less than 10%. As either the length of the reference period or the frequency of occurrence increases, fewer respondents rely on recall and enumeration. Of 140 respondents reporting more than ten restaurant visits, none used this approach (27).

How, then, do people answer these kinds of questions? In general, respondents will use any information they have in order to generate a reasonable answer (19, 39, 42). Two

strategies, however, seem especially prevalent. The first involves "decomposing" the problem into subparts. For example, in answering the question about restaurant visits, most respondents first determined a rate of occurrence and then multiplied the rate to arrive at a quantity for the requested time period (27). The same pattern has been observed independently in our work: a typical answer is "about twice a week, which would be eight times in the last month." Another decomposition approach is to determine values for mutually exclusive and exhaustive components of the desired quantity (for example, separate values for restaurant breakfasts, lunches, and dinners). Both multiplicative (rate-based) and additive decomposition have been observed in survey responding (7). In general, decomposition can be an effective technique for improving the accuracy of quantitative estimates (43), and thus offers potential for improving the accuracy of survey responses when it fails to occur naturally (44).

A second inferential strategy relies on the pure bulk of recalled information. The more people can recall (or the more easily they can bring associated facts to mind), the more frequent, likely, or recent an event will seem. This judgment process, called the availability heuristic (45), causes quantitative errors in many domains: mistakes in estimating frequencies of English words (45) and of causes of death (46); misperceptions of individuals' contributions to collaborative work (47); and incorrect dating of headline events (48). Questions that seek information without prior warning--including most survey questions--are especially susceptible to availability bias (49).

Respondents' answers also contain hints of other inference types. For instance, people's knowledge of normative expectations (for example, twice yearly dental checkups) and their awareness of their own deviations ("I

don't go as often as I should') influence responses. Other strategies that we observe in protocol studies are interpolation between a largest and smallest plausible value (for example, a Chicago subject asked about the distance from City Hall to Lake Michigan responded, "The farthest reach of that [downtown] area is probably two miles, so since it's in there somewhere I'll say one mile') and relational reasoning (for example, asked what the duration of a nonstop flight from Dallas to Seattle would be, the subject answered, "It's probably a little bigger distance than . . . from here to my home, . . . so I'd say 4 hours'). Initial estimates often are corrected up or down, an example of the so-called "anchor and adjustment' heuristic (50).

### **Inference Processes and Their Implications for Surveys**

In many cases, a respondent remembers a few facts pertinent to a survey question and then produces an answer using some kind of inductive inference. There is, in fact, no generally accepted theory of this kind of reasoning in either psychology or philosophy. Most of the inferences of concern in the present context, however, are ones whose conclusion offers an explanation of why certain facts are remembered and others not (51). Many cases of decomposition seem to fit this framework. A respondent who can recall three dental visits in the last 3 months may reason that these visits reflect an underlying rate of one per month and, therefore, that the number of visits in the last year is 12.

Many such inferences are based on lay explanations about the nature of memory. People realize, for instance, that recall of an event may be difficult or impossible if the event happened infrequently, long ago, or not at all. Thus, when they must answer a question about an event and find that they are having trouble recalling pertinent information, they may use their beliefs about memory to

conclude that the event was an infrequent one (45, 46), that it happened long ago (48), or that it simply did not occur (42, 52). Such inferences are often correct, but in some situations lead to errors, in part because the lay explanations are incomplete or misleading accounts of memory dynamics.

This type of reasoning may be responsible for a well-known phenomenon called "telescoping' that affects survey responses to questions about the frequency of events within a given reference period (41, 53). Telescoping occurs when respondents mistakenly import into the reference period events that actually happened earlier. For example, a respondent might incorrectly count a visit to a dentist that occurred 15 months ago in answering the question "How many times did you see a dentist in the last twelve months?" One way to explain telescoping is to suppose that respondents recall incidents of the required type (for example, dental visits) but are unable to remember their exact dates. If they recall an incident that actually occurred before the reference period but the memory is especially detailed, then the respondents may incorrectly infer that the incident was recent enough to be within the interval. The mistake occurs because they gauge recency, in part, by the clarity of their memory, without taking into account factors other than time (for example, distinctiveness or initial impact) that can also affect recall. Support for this theory comes from experimental results, summarized in Fig. 4, demonstrating that people give public events too recent a date if they can remember many details about them and too early a date if they recall relatively little (48). Further, if the subjects rate their knowledge of the events before dating them, they tend to give more recent dates than if they date the events first. This is consistent with the assumption that the rating task increases the ease and clarity with which the subjects subsequently recall the events, making the events appear more recent.

Additional research shows that especially salient personal events are also given too recent a date (17).

The autobiographical sequences mentioned earlier may sometimes be helpful in offsetting the effects of faulty inferences. Because these sequences anchor events onto a personal time frame, they can provide additional clues about dates beyond those based on ease or detail of recall. One strategy that survey methodologists employ to reduce telescoping is "bounded recall" (53) in which the data from one interview are used as cues for recall in the next time period. Surveys such as the National Medical Care Expenditures Survey and the Consumer Expenditure Survey use bounded recall when respondents report on events over an extended interval (typically 1 year) but are interviewed periodically (typically every 3 months) about expenditures during the period. The interviewer gives the data from the previous time period to the respondents and asks about expenditures occurring since the last interview. The previous interview acts as a landmark, and the data from the previous period act as cues to reduce recall of events from the wrong period. It is an effective method for reducing telescoping errors, but the cost discourages widespread use. As an alternative possibility, survey designers might invoke autobiographical sequences by asking how many events happened since a salient calendar break or since a personally important public or autobiographical event, rather than "in the last 3 months." One experiment showed significantly reduced telescoping by means of such rephrasings (54).

### **Summary and Conclusions**

Survey researchers are often after the kind of quantitative, autobiographical information that taxes even the most cooperative respondents' mental abilities. Recall is not dependable. Inference, which helps fill in

details that respondents cannot recall, is at best inexact and at worst misleading. Understanding these cognitive limitations can improve the accuracy of surveys.

Recent experiments on autobiographical memory suggest that people often recall incidents as parts of autobiographical sequences --coherent streams of events. If this type of organization predominates, it may be difficult for respondents to answer questions that center on the time of occurrence of events (for example, incidents that happened in the last 3 months) or on abstract descriptions (for example, number of "visits to a health-care professional"). More successful questions might center on particular sequences or might use sequences as reference points for locating other facts of interest.

Cognitive research makes it clear that inference plays an inevitable role in responding. In many situations of importance in survey work, respondents are simply unable to retrieve and count separate incidents. Instead, they use the fragmentary information that they have and extrapolate as necessary. They often decompose the question to make better use of the information that they do recall. Sometimes they even use as a guide the sheer number of facts that they find. In any event, the answers are likely to be biased by the assumptions that the respondents apply to the problem and by the computational difficulty of the resulting inferences. Studying respondents' strategies is a productive way to understand these errors and to learn more about the underlying nature of autobiographical memory.

### **REFERENCES AND NOTES**

1. National Center for Health Statistics, Current Estimates from the National Health Interview Survey, United States, 1983 (Vital and Health Statistics, Government Printing Office, Washington, DC, 1986), series 10, no. 154.

2. U.S. Bureau of the Census, Characteristics of the Population Below the Poverty Level: 1984 (Current Population Reports, Government Printing Office, Washington, DC, 1986), series P-60, no. 152, p. 145.
3. J. A. Davis and T. W. Smith, General Social Surveys, 1972-1986:  
Cumulative Codebook (National Opinion Research Center, Chicago, 1986), p. 128.
4. G. J. Duncan and J. N. Morgan, Eds., Five Thousand American Families--Patterns of Economic Progress (Institute for Survey Research, Ann Arbor, MI, 1983), p. 408.
5. This survey is available from the Division of Consumer Expenditure Surveys, Bureau of Labor Statistics, Department of Labor, Washington, DC 20212.
6. National Science Foundation, A Guide to NSF Science/Engineering Resources Data (Washington, DC, 1984), p. 43.
7. R. Tourangeau, J. Lessler, W. Salter, Cognitive Aspects of Questionnaire Design: Part C (Technical Report, National Opinion Research Center, Chicago, 1986).
8. M. Linton, in Explorations in Cognition, D. A. Norman and D. E. Rumelhart, Eds. (Freeman, San Francisco, 1975), p. 376.
9. ----, in Memory Observed, U. Neisser, Ed. (Freeman, San Francisco, 1982), p. 77.
10. S. E. Fienberg, E. F. Loftus, J. M. Tanur, Milbank Mem. Fund Q. 63, 547 (1985); T. B. Jabine, M. L. Straf, J. M. Tanur, R. Tourangeau, Eds., Cognitive Aspects of Survey Methodology: Building a Bridge between Disciplines (National Academy Press, Washington, DC, 1984); J. T. Lessler and M. G. Sirken, Milbank Mem. Fund Q. 63, 565 (1985); R. Tourangeau and K. A. Rasinski, "Cognitive processes underlying context effects in attitude measurement," paper presented at the National Opinion Research Center Conference on Context Effects in Surveys, Chicago, 15 and 16 July 1986.
11. P. V. Miller "Interviewing behavior as response context," paper presented at the National Opinion Research Center Conference on Context Effects in Surveys, Chicago, 15 and 16 July 1986.
12. S. Sudman and N. M. Bradburn, Response Effects in Surveys: A Review and Synthesis (Aldine, Chicago, 1974).
13. ----, Asking Questions (Jossey-Bass, San Francisco, 1982).
14. N. M. Bradburn et al., Improving Interview Method and Questionnaire Design: Response Effects to Threatening Questions in Survey Research (Jossey-Bass, San Francisco, 1979).
15. P. E. Converse and M. W. Traugott, *Science* 234, 1094 (1986).
16. S. E. Fienberg, E. F. Loftus, J. M. Tanur, Milbank Mem. Fund Q. 63, 582 (1985).
17. W. A. Wagenaar, *Cognit. Psychol.* 18, 225 (1986).
18. H. P. Bahrick, P. O. Bahrick, R. P. Wittlinger, J. Exp. Psychol. Gen. 104, 54 (1975).
19. A. D. Baddeley, V. Lewis, I. Nimmo-Smith, in Practical Aspects of Memory, M. M. Gruneberg, P. E. Morris, R. N. Sykes, Eds. (Academic Press, New York, 1978), p. 77.
20. H. P. Bahrick, in Psychology of Learning and Motivation, G. H. Bower, Ed. (Academic Press, New York, 1983), vol. 17, p. 125.
21. C. P. Thompson, *Mem. Cognit.* 10, 324 (1982).
22. W. B. Whitten, II, and J. M. Leonard, *ibid.* 9, 566 (1981).
23. M. D. Williams and J. D. Hollan, *Cognit. Sci.* 5, 87 (1981).
24. From the events Wagenaar (17) judged to be completely forgotten, he selected some that crucially involved other people. He interviewed these people, and in every case they provided additional cues that enabled recall of the event.
25. It has also been shown that respondents' answers to open-ended questions on the telephone are shorter than in a face-to-face interview [R. M. Groves and R. L. Kahn, *Surveys by Telephone: A National Comparison with Personal Interviews* (Academic Press, New York, 1979)].
26. B. J. Reiser, J. B. Black, R. P. Abelson, *Cognit. Psychol.* 17, 89 (1985).
27. S. Burton and E. Blair, *Proc. Am. Stat. Assoc.* (1986).

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28. C. F. Cannell, L. Oksenberg, J. M. Converse, J. Mark. Res. 14, 306 (1977).
29. A. D. Baddeley and G. J. Hitch, in *Attention and Performance*, S. Dornic, Ed. (Erlbaum, Hillsdale, NJ, 1977), vol. 6, p. 647.
30. U. Neisser, *Cognition* 9, 1 (1981).
31. L. W. Barsalou, in *Real Events Remembered: Ecological Approaches to the Study of Memory*, U. Neisser, Ed. (Cambridge Univ. Press, Cambridge, in press).
32. W. Horn, *Het PTT-Bedrieff* 10, 105 (1960).
33. E. F. Loftus and D. C. Fathi, *Soc. Cognit.* 3, 280 (1985).
34. D. B. Pillemer, E. D. Rhinehart, S. H. White, *Hum. Learn.* 5, 109 (1986).
35. D. C. Rubin and M. Kozin, *Cognition* 16, 81 (1984).
36. R. Brown and J. Kulick, *ibid.* 5, 73 (1977); D. B. Pillemer, *ibid.* 16, 63 (1984); E. Winograd and W. A. Killinger, Jr., *J. Exp. Psychol. Gen.* 112, 413 (1983); A. D. Yarmey and M. P. Bull, III, *Bull. Psychon. Soc.* 11, 133 (1978).
37. In previous work [N. R. Brown, S. K. Shevell, L. J. Rips, in *Autobiographical Memory*, D. C. Rubin, Ed. (Cambridge Univ. Press, Cambridge, 1986), p. 137], we referred to these sequences as "autobiographical narratives." A related concept is "extended event time lines" (31).
38. J. A. Robinson, in *ibid.*, p. 159.
39. N. R. Brown, S. K. Shevell, L. J. Rips, *ibid.*, p. 137.
40. A. Lieury, B. Aiello, D. Lepreux, M. Mellet, *Annee Psychol.* 80, 149 (1980).
41. S. Sudman and N. M. Bradburn, *J. Am. Stat. Assoc.* 68, 805 (1973).
42. A. M. Collins, in *Theoretical Issues in Natural Language Processing*, D. Waltz, Ed. (Association for Computing Machinery, New York, 1978), vol. 2, p. 194.
43. J. S. Armstrong, W. B. Denniston, M. M. Gordon, *Organ. Behav. Hum. Perform.* 14, 257 (1975); D. MacGregor, S. Lichtenstein, P. Slovic, *Structuring Knowledge Retrieval* (Report 84-14, Decision Research, Eugene, OR, 1984).
44. A. W. Siegel, L. T. Goldsmith, C. R. Madson, *J. Res. Math. Educ.* 13, 211 (1982).
45. A. Tversky and D. Kahneman, *Cognit. Psychol.* 5, 207 (1973).
46. S. Lichtenstein, P. Slovic, B. Fischhoff, M. Layman, B. Combs, *J. Exp. Psychol. Hum. Learn. Mem.* 4, 551 (1978).
47. M. Ross and F. Sicol, *J. Pers. Soc. Psychol.* 37, 322 (1979).
48. N. R. Brown, L. J. Rips, S. K. Shevell, *Cognit. Psychol.* 17, 139 (1985).
49. R. Hastie and B. Park, *Psychol. Rev.* 93, 258 (1986).
50. A. Tversky and D. Kahneman, *Science* 185, 1124 (1974).
51. G. Harman, *Change in View: Principles of Reasoning* (MIT Press, Cambridge, MA, 1986).
52. D. Gentner and A. Collins, *Mem. Cognit.* 9, 434 (1981).
53. J. Neter and J. Waksberg, *J. Am. Stat. Assoc.* 59, 18 (1964).
54. E. F. Loftus and W. Marburger, *Mem. Cognit.* 11, 114 (1983).
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