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BIASED PROBING OF MEMORY: A NEW EXPLANATION OF HINDSIGHT BIAS

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Table of Contents

List of Tables

Table of Illustrations

Abstract

The following research explores how biased probing of memory leads to overestimating the accuracy with which one could have predicted past events, the hindsight bias. MINERVA-DM, a multiple trace model developed by Dougherty, Gettys, and Ogden (1999), suggests that the probing of memory with detailed versus sketchy probes leads to a hindsight bias. When making probability judgments concerning an event that has already occurred we tend to probe memory with a highly detailed probe. We use sketchy probes for alternative events that might have happened but did not. This asymmetry in the amount of detail in the probes leads to an excessive feeling of certainty for what actually happened, and reduces the feelings of certainty for alternative outcomes.

Two experiments were conducted examining the effects of biased probing on the hindsight bias. Experiment 1 systematically varied the amount of detail used to probe memory. It was found that the more detailed outcome knowledge was, the more excessive the bias. Experiment 2 examined what participants forgot about a sporting event, and how forgetting affected the hindsight bias.

Participants forgot more details of outcomes for "what might have happened, but did not." This differential forgetting created the asymmetry in the details of the probes, and produced the hindsight bias.

Introduction

Individuals often overestimate the accuracy with which they could have predicted past events – viewing what has already happened as relatively inevitable and obvious. For example, a researcher may regard the findings of his/her research as having been predictable all along. If asked to estimate retrospectively how likely the results were to occur, he/she often assigns higher probabilities than would another person predicting the same experimental outcome in advance. This propensity to distort one's judgment retrospectively in the direction of outcome information is called the hindsight bias or the "knew-it-all-along" effect.

Fischhoff (1975) conducted one of the first studies on the hindsight bias. He provided participants with vignettes describing either a historical or clinical event (e.g., one vignette described war between the British and the Gurkas of Nepal). The last sentence in the vignette described a possible outcome to the war, and participants were led to believe it was the actual outcome. After reading the vignette, they were asked to estimate the likelihood of four possible outcomes, one of which was the last sentence in the vignette. Fischhoff found participants tended to rate the outcome they believed had occurred as having been more likely than the alternatives that they thought did not occur.

This bias affects everyday people in a wide variety of situations. Doctors, lawyers, and managers have been shown to over-estimate the predictability of an event based upon retrospective knowledge. For example, the hindsight bias has been found to affect judgments concerning elections (e.g.,Dietrich & Olson, 1993; Leary, 1982; Synodinos, 1986), medical diagnoses (Arkes, Wortmann, Saville, & Harkness, 1986), and pregnancy tests (Pennington, Rutter, McKenna, & Morley, 1980) as well as many other areas. Furthermore, the hindsight bias has been used to explain individuals' perceptions of historical events, such as the Clinton impeachment verdict (Bryant & Guilbault, 2002), the O.J. Simpson trail (Demakis, 1997, Schmolck, Buffalo, & Squire, 2000), the Rodney King incident (Gilbertson, Dietrich, Olson, & Guenther, 1994), and the nuclear accident at Chernobyl (Verplanken & Pieters, 1988).

Understanding this bias is of practical importance because it can lead to significant consequences. Without realizing that retrospective knowledge influences judgment, a person may be prone to believing that his/her opinions are more accurate than they really are, thus becoming overconfident. Also, it may lead an individual to devalue the opinions of others who did not predict the event, and/or to overvalue the opinions of those who did. Furthermore, the hindsight bias may cause a failure to properly update one's knowledge, and could lead to failure to recognize the need to improve one's judgments.

The hindsight bias is a robust effect. It has been shown to be unaffected by telling people to work harder (Fischhoff, 1977), or by manipulating the individual's perspective (i.e., making judgments as others would; Wood, 1978). Even awareness of the bias does not affect its existence (Fischhoff, 1977). For example, Bond-Raacke et al. (2001) used subjects from a psychology class that had previously studied the hindsight bias. The subjects' awareness of bias did not prevent them from committing it. Because of its tenacity there is a need to develop an understanding of the processes involved in this bias, and to what extent they modulate its magnitude.

Possible explanations

Explanations of processes underlying the hindsight bias are divided into two basic categories: motivational factors (i.e., self-flattery or desire to appear intelligent) and cognitive factors. See Hawkins and Hastie (1990) and Christensen-Szalanski and Willham (1991) for in-depth reviews of these explanations.

Motivational factors.

Individuals may be motivated to look good (i.e., appear intelligent and knowledgeable). Persons may employ strategies that bias their judgments in such a way that they appear to make better predictions than if asked to do so in advance. Most researchers consider the effects of motivational factors to be relatively small because the hindsight effect is so robust (Connolly & Bukszar, 1990; Fischhoff & Beyth, 1975; Leary, 1981, 1982; Wood, 1978).

Campbell and Tesser (1983) investigated the influence of the predictability motive (the desire to know and be able to predict the environment accurately) and the self-presentation motive (a need to maintain private and public esteem) on the hindsight bias.

While they did find that motivational factors were significantly correlated with the degree of bias, these factors could only account for 6% of the variance in the bias. In other research, Leary (1981, 1982) found no effect of a high or low ego-involvement in non-laboratory settings. Synodinos (1986) found that individual differences in self-esteem and political involvement did not play a role in hindsight.

At best motivational factors play a role in modulating the magnitude of the bias. They have not been shown to eliminate or produce it (i.e., providing incentives does not eliminate the bias). Thus, motivational factors have a very limited impact on judgments.

Cognitive Factors.

Most researchers have concluded that cognitive factors play a greater role in the hindsight phenomenon. Current thinking hypothesizes that the hindsight bias is simply a natural by-product of the normal process by which information is integrated, stored and/or retrieved from memory (Connolly & Bukszar, 1990; Dougherty, Gettys & Ogden, 1999). However, to date there have been relatively few studies attempting to isolate these cognitive processes (Hawkins & Hastie, 1990; Christensen-Szalanski & Willham, 1991). Cognitive factors that have been examined include: direct recall, anchoring and adjustment, memory impairment, and reconstruction. These will briefly be discussed in the following section.

Direct Recall. One explanation is that individuals may directly recall old beliefs (Hawkins & Hastie, 1990). For example, an individual may search his/her memory and respond consistently with his/her original rating. This is an issue for studies that use a *memory-based* methodology (Werth, Strack, & Forester, 2002). Using this methodology, participants are asked to recall subjective likelihood judgments that they made earlier after exposure to outcome knowledge or feedback. In other words, participants are asked to make the same judgment twice. Memory designs tend to produce smaller hindsight bias effects, because participants have the possibility of recalling their earlier estimates. However, while the results are smaller, participants do consistently produce a bias.

While direct recall may be a possibility, Hell, Gigerenzer, Gauggel, Mall, and Mueller (1988) found that in order for the hindsight bias to occur participants must forget their original estimation. Instead, it appears that deeper encoding for the original estimate leads to a decrease in the bias. In fact, Creyer and Ross (1993) found that greater cognitive effort enhanced participants' memory for the previous decisions, and thus decreased the bias.

Anchoring and Adjustment. Another explanation involves anchoring and adjustment based on outcome knowledge (Fischhoff, 1977; Hawkins & Hastie, 1990). This explanation assumes participants anchor on 100% certainty after being told that a particular outcome has occurred, and then adjust their certainty downward towards their retrospective judgment.

This explanation, however, does not work well. As with direct recall, participants must be able to recall previous judgments in order to adjust. And as was mentioned earlier, the recall of an original response actually decreases the bias (Creyer & Ross, 1993; Hell et al., 1988). Furthermore, individuals do not appear to anchor and adjust the alternative outcomes (those events that could have happened, but did not). Biases for alternative outcomes are much smaller and closer to participants' original estimates than biases for outcomes that "actually occurred" (Fischhoff, 1977; Fischhoff & Beyth, 1975; Woods, 1978). In other words, people are less likely to adjust their judgments when told an event did not occur.

Memory Impairment. Several memory-based approaches imply that the hindsight bias is the result of retrieving a memory trace that has been changed or altered after the outcome knowledge (actual value) has been encoded (Fischhoff, 1975; Loftus, 1975). In the past, it has been thought that an event is stored in a single memory trace and that new information is assimilated into the old trace. Fischhoff (1975, 1977), postulated that outcome knowledge is immediately assimilated into what is already known about the event, and that no trace of the original information is left in memory. This process occurs automatically as an individual attempts to make sense of all relevant information concerning an event.

Therefore, the memory impairment explanation implies storage of a faulty memory trace. An individual only stores a single version of the event in memory (Loftus & Loftus, 1980), and the process of updating and erasing causes this memory trace to be faulty. Thus, the hindsight bias results from the retrieval of a faulty (altered) memory trace from LTM.

Reconstruction. Finally, participants may use rejudgment or reconstruction of the outcome. Here participants reconstruct prior judgments using their outcome knowledge as retrieval cues (Hawkins & Hastie, 1990; McCloskey & Zaragoza, 1985; Stahlberg & Maas, 1998; Schwartz & Stahlberg, 2003; Werth, Strack, & Forster, 2002). This explanation involves primarily three steps. First, an individual searches LTM for evidence relevant to the task. Evidence that does not fit the outcome that has occurred becomes less accessible and is not retrieved. Second, the evidence is evaluated for arguments for and against the outcome happening. These arguments and the outcome that actually happened are assimilated into memory forming links to casual relations within the individual's knowledge structure. Third, the evidence is weighted and combined to produce an overall judgment (Hawkins & Hastie, 1990).

According to this approach, outcome knowledge is used to reconstruct the "original judgment" (Schwartz & Stahlberg, 2003). The original information is not lost, erased nor rendered inaccessible by the outcome knowledge (McCloskey & Zaragoza, 1985). For example, Schwartz and Stahlberg (2003) demonstrated that the outcome information had no effect on individual's ability to recall their initial judgment. Instead, either the original information, or the outcome knowledge could be used to make the judgments.

The debate between memory impairment and reconstruction is similar to the one between Loftus (1975, 1979) and McCloskey & Zaragoza (1985) within the field of eyewitness testimony. Loftus (1975; 1979; Loftus & Loftus, 1980) believed that the misleading information effect was due to the misleading information overwriting (or replacing) the original information in memory. The original information was automatically updated when subsequent misleading information was encountered (destructive updating). Thus, the original information was lost forever and could not be retrieved. On the other hand, McCloskey and Zaragoza (1985) felt that the original information was neither lost nor rendered inaccessible. Instead, the misleading information effect occurs when outcome knowledge is used to reconstruct the original event. The original information, outcome knowledge or both could be used during this reconstruction process.

In summary, the first three explanations (motivation, direct recall, and anchoring and adjustment) do not work well. In fact, previous research has either eliminated them as explanations for the hindsight bias or shown them to be only mitigating factors (affecting the magnitude of the bias). Current research, however, has been unable to eliminate either the memory impairment or the reconstruction approach (Stahlberg and Maass, 1998; Pohl, Eisenhauer, & Hardt, 2003; Schwartz and Stahlberg, 2003). Further, it has been concluded that memory impairment and biased reconstruction are not mutually exclusive, and that both may lead to the hindsight bias.

Specificity of the Probe

Dougherty, Gettys and Ogden (1999) derived an alternative explanation for the hindsight bias using the global memory matching model, MINERVA-DM. Their explanation involves a biased probing of memory that results from the use of a highly-detailed memory probe. This explanation may provide a mechanism for the first step in the reconstruction explanation in which an individual searches LTM for evidence that is relevant to the task.

The new explanation proposes that an individual does not *just* search LTM, but instead uses probes that vary in the amount of detail to conduct the search. The idea is that the details in the probes are brought into working memory via the decision task itself, retrieval from LTM, or internal generation. The probe for "what actually occurred" is highly detailed because the actual outcome-scenario is used as the retrieval cue. Memories for real events tend to contain more sensory, spatial, temporal, and affective information, compared to those that have been internally generated (Johnson & Raye, 1981). The probes for alternative outcomes that "might have happened, but did not" are much less detailed. These probes rely heavily on an internal scenario-generation process, which is assumed to produce less detail.

Probing LTM with a very detailed probe would match more traces (a larger subset of memory) than a less detailed probe. This would result in an inflated level of certainty; thus, producing the hindsight bias. This explanation asserts that an asymmetry in the amount of details contained in the probes leads to an excessive feeling of certainty for what actually happened, and reduced feelings of certainty for what might have happened but did not.

Exaggerating this problem is the possibility that a disproportionate amount of details are forgotten over time for the alternative outcomes (differential forgetting). Details for the alternative hypotheses may be forgotten at a much higher rate than details for what actually happened. Further, individuals may revisit memories for "what happened," thus reinstantiate these memories.

In summary, probes for "what actually happened" are more detailed because they are based on memories for real events, and they may be reinstantiated over time. Hence they are less likely to be forgotten. In contrast, probes for alternative outcomes are less detailed because they tend to be internally generated, and they may be forgotten at a higher rate over time.

Description of MINERVA-DM

This explanation arises from a quantitatively-specified memory model for decision making called MINERVA-decision making (DM). MINERVA-DM is a modified version of Hintzman's (1984; 1988, 1990) MINERVA2 memory model for frequency judgments and recognition memory. The following is a brief description of MINERVA-DM. For a more detailed, computational explanation of the model refer to Dougherty, Gettys, and Ogden (1999). Also, refer to Appendix A for the source codes to a computer program used simulate the model.

MINERVA-DM is a multiple-trace memory model that assumes stimuli are encoded into long-term memory (LTM), but specific traces are less than perfect replicas of stimuli. Each experienced event is encoded as a separate memory trace. MINERVA-DM represents traces in memory as vectors made up of a series of +1, -1, or 0's. Zeros correspond to a feature that is either unknown or irrelevant. The value -1 corresponds to a feature that is inhibitory, and the value +1 corresponds to a feature that is excitatory.

A learning (L) parameter is used to determine the degree to which traces encoded into memory are exact replicas of the event vectors. Each feature in an event vector is copied into LTM with probability L ($0 < L < 1$). This allows traces to match the original events to varying degrees. It also means multiple traces of a repeated item may not be stored in exactly the same manner. L is affected by length of exposure, number of exposures, attention, perceptual acuity, and so on.

Memory is assessed by using a memory probe, a retrieval cue which specifies which type of information is to be retrieved from memory. The MINERVA-DM probe is also a vector of +1, -1, and 0's. All traces in LTM are activated simultaneously by the probe. The similarity, S, between the probe and each trace, *i*, in memory is assessed.

$$S_i = \frac{\sum_{j=i}^{N} \mathbf{P}_j \mathbf{T}_{i,j}}{N_i} \qquad (1)$$

P_j corresponds to feature *j* in the probe, $T_{i,j}$ corresponds to feature *j* in trace *i*, and N_i is the number of corresponding nonzero features in both the probe and the trace *i*. Thus, if either one or both (P_j or $T_{i,j}$) is nonzero, the N_i is incremented. If either P_j or $T_{i,j}$ is zero, the product will be zero and nothing will be added to the numerator of Equation 1. Zeros in the vectors tend to reduce similarity. Thus, similarity can have a negative or positive value.

The activation of a single memory trace is the simularity cubed:

$$A_i = S_i^3 \tag{2}$$

This cubing function allows traces that are highly similar to the probe to dominate by giving them more weight than traces that are only somewhat similar. Further, the sign of activation is preserved.

The output of the model, echo intensity, is the sum of the activations (cubed similarities) over all traces in LTM.

$$I = \sum_{i=1}^{M} A = \sum S^3 \tag{3}$$

M is the number of traces assessed for similarity. Echo intensity is proportional to judged likelihood. It increases as the frequency of similar traces stored in memory increases.

To recap, if an individual is asked to assess the likelihood of an event occurring (i.e., the sinking of the Titanic), he/she must create at least two probes (the Titanic sank versus the Titanic stayed afloat). Then the probes are used one at a time to evaluate LTM. The similarity between each probe and each trace is assessed. For each probe, the sum of the cubed similarities (echo intensity) over all LTM traces is calculated. Echo intensity for each scenario is then used to make estimates of likelihood.

Level of Detail in the Probe. As mentioned above, level of detail in the memory probes is important to MINERVA-DM's explanation of the hindsight bias. This explanation specifies that the level of detail of a probe is greater for the event that is said to have "actually happened." The probes for alternative outcomes are less detailed.

MINERVA-DM specifies the amount of detail by a G parameter. This parameter can vary from 0 to 1.0. Each detail of the scenario is copied to the probe with a probability of 1 – G that it will be converted to a 0. If, for example, G = 1.0, all details of the scenario are retained in the probe and no features are converted to 0s. Probing long-term memory with a detailed cue returns a relatively large echo intensity. If, on the other hand, G = 0.5, then half of the +1 and -1's in the probe vectors are converted to 0's.

This would reduce the similarity between the probe and the traces in memory and therefore reduce echo intensity (refer to Figure 1). It is assumed that the probe for "what did happened" is highly detailed and the probe for "what might have happened but didn't" (the alternative outcome) is less detailed. The G parameter is used to vary the amount of details in the probe and thus, simulate biased probing of LTM by degrading the memory probe.

According to MINERVA-DM, the biased probing of LTM with highly-detailed probes results in an elevated level of similarity, which in turn results in an inflated level of certainty and a hindsight bias. It is believed that the probe for "what actually happened" is highly detailed because the actual outcome-scenario is used as the retrieval cue. The probes for "what might have happened but did not" are much less detailed because these probes rely on a scenario-generation process; the details must be generated internally and filled in by the individual.

There are several possibilities for why the probe for "what actually happened" is more detailed. First, it occurred recently, and has had little time to decay. Second, it was experienced rather than imagined, and thus, contains more information, compared to those that have been internally generated (Johnson & Raye, 1981). Third is the possibility of differential forgetting – over time, details for the alternative scenarios will fade faster than details for the actual scenario. Individuals may "revisit" the event in memory for what actually happened. For example, watching various documentaries about the Titanic, reading books about it, discussing it, etc., allows a person to revisit details about how the Titanic sank. Fourth, few details are provided for the alternative outcomes, because they tend to be internally generated. For example, the media has provided a plethora of details concerning the Titanic and why she may have sunk (design flaws, poor judgment by crew, pressure to break a speed record, massive death toll, an iceberg, and so on), and relatively few details for how she might have been saved.

Purpose of Current Research

The aim of the present research was to examine the biased probing of memory explanation, and to provide an empirical test of the MINERVA-DM model. The first experiment was based on a vignette paradigm, so comparisons could be made to past research, and so the level of details in an outcome could be systematically manipulated. A second study was conducted using a more "real world" task. Further, the second experiment examined the effect of differential forgetting on likelihood judgments. The results from both experiments were compared to simulations produced by MINERVA-DM.

Experiment 1

The purpose of Experiment 1 was to examine the effect of varying the level of detail in outcome knowledge. The use of vignettes, small literary sketches, is a typical methodology employed to study the hindsight bias. In past studies, the experimental task provided all retrieval cues to the participants and may have unwittingly biased the participants' memory probes by providing more detail for what actually happened. For example, Fischhoff (1975) had subjects read a short paragraph about the war between the British and the Gurkas of Nepal. The last sentence in the paragraph stated the outcome. Then subjects were asked to rate the likelihood of that outcome as well as three alternative outcomes (each only one sentence long). This may have created an asymmetry with which the subjects could probe their memories (a paragraph for the "actual" outcome and a sentence for the alternatives).

Experiment 1 attempted to produce the biased probing effect using a vignette paradigm. The level of detail was manipulated by varying the amount of detail in the "actual" outcome and in a possible alternative outcome across several vignettes. MINERVA-DM predicts that the hindsight bias should be reduced as the level of details in the actual and alternative outcome approach each other. The hindsight bias should be the greatest when "actual" outcome is highly detailed and the alternative outcome is sketchy.

Two simulations were performed using MINERVA-DM. In the first simulation, G (a parameter that specifies the amount of detail in the memory probes) was set to 0.4. This simulates a situation where the probe for the actual outcome scenario is highly detailed and the probe for what did not occur has relatively few details. In the second simulation, G was set to 0.8, and simulates situations where both probes (for what actually happened and for what did not) have relatively high levels of details. There were

1000 simulated participants. The learning parameter was set to 0.75.

Figure 2 presents the results from the simulations. As can be seen, when G is set to 0.4 the magnitude of the hindsight bias is more pronounced. Thus, the hindsight bias should be most pronounced when participants use a very detailed probe for "what actually happened" and a sketchy probe for the alternative.

Also, this experiment tried to lessen or eliminate the hindsight bias. If increasing the level of detail in the "actual" outcome magnifies the hindsight bias, then increasing the level of detail in the alternative outcomes (the ones that might have happened but did not) may reduce or eliminate the bias.

Method

Participants. Participants (n = 206) were recruited from the psychology department's student subject pool at the University of Oklahoma, and received course credit for participation. Participants were tested individually using a computer program. Participants were randomly assigned to one of the experimental conditions: foresight (n = 92) and hindsight (n = 114) conditions.

Stimulus Materials. Four vignettes were developed describing fictional patients and their symptoms. The symptoms for each vignette were chosen because they equally conformed to either of two possible diagnoses (i.e., the patient could develop tuberculosis or Hodgkin's disease). The diagnosis descriptions were designed so that they were mutually exclusive.

For each diagnosis, two versions of the outcome were developed—one highly detailed, and one sketchy (see Figure 3). This allowed the experimenter to systematically vary the amount of detail in the "actual"[1] and alternative[2] outcome pairings, and for each possible comparison combination to be randomly generated. Outcome details consisted of various medical procedures used to form the diagnosis, medical regime used to treat the disease, outcome of treatment, and long-term prognosis for the patient. The highly detailed version contained 44 +/- 3 unique concepts

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[1] The term "Actual" refers to the outcome participants are led to believe occurred (are told happened). It is not a correct answer or a veridical probability.

(400 +/- 3 words) and the sketchy versions 12 +/- 1 concepts (50 +/- 2 words).

Vignettes and outcomes were selected on the basis of a norming study carried out on 23 participants. This norming study was conducted to select pairs of high detail outcomes and pairs of sketchy detail outcomes that were not significantly different from each other in likelihood judgments. No comparisons were made between high and low outcome pairings in the norming study. Participants read only the outcomes (no patient information, symptom, and so on), and they were not told which outcome was true. For the norming study, the mean likelihood judgment for high-detailed outcomes was M = 54.33, and for low-detailed outcomes M = 52.83. There was no statistically significant difference.

Procedure. For each vignette, participants first read the patient and symptom description, and then they read the possible outcomes (one outcome for each diagnosis). Participants read one

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[2] The term "alternative" refers to the outcome that "might have happened, but did not."

vignette for each of the possible detail-level combinations: 1) both outcomes were highly detailed (HH), 2) both outcomes were sketchy (LL) 3) the "actual" outcome was highly detailed and the alternative was sketchy (HL) and 4) the "actual" outcome was sketchy, and the alternative was highly detailed (LH). Thus, each participant read a total of four vignettes. Refer to Table 1 for a summary of the detail-level pairings.

The foresight group proceeded directly to making the likelihood judgments for each outcome, and was not told which outcome had occurred. The hindsight group read a brief statement telling which of the two outcomes "actually" occurred, and then made their likelihood judgments. Hindsight participants were asked to answer the likelihood judgments as they would have done in the absence of the outcome knowledge.

A computer program randomly administered the vignettes, detail level and order of their occurrence, and solicited the appropriate likelihood ratings. This was done to eliminate any order and vignette effects. Participants made likelihood judgments by sliding a cursor across a likelihood scale displayed on the computer. The scale ran from 0% to a 100%. Participants were told to move the cursor on the scale to indicate how likely they felt the outcome was to have occurred. The experimental procedure was self-paced in that participants were given as much time as needed to read the vignettes and to make the judgments. The entire experimental session lasted from 10 to 15 minutes.

Dependent measures. Participant made two likelihood judgments for each detail-level scenario pairing (HH, LL, HL, and LH): one for the "actual" outcome, and one for the "alternative". The amount of time taken to read each outcome was measured.

Results

Reading Times. A paired two-sample t-test found that the average amount time spent reading high-detail outcomes M = 39.95 seconds, SD = 14.32) was statistically significantly different {$t_{(205)} = 8.59$, $p < 0.0001$) from time spent reading low-detail outcomes (M = 19.96 seconds, SD = 30.04).

Actual Outcome. For likelihood judgments concerning the actual outcomes, a 2 (hindsight, foresight) X 4 (detail-level scenario pairing: HL, HH, LL, LH) split-plot factorial ANOVA was performed. The hindsight-foresight manipulation was the between subjects factor, and detail-level scenario pairings was the within-subject factor.

The hindsight-foresight manipulation revealed a significant main effect [$F_{(1, 204)} = 131.79$, $p < 0.0001$]. This result indicates that a hindsight bias was produced. The hindsight group showed significantly higher likelihoods than the foresight group (see Figure 4).

The detail-level scenario pairing manipulation revealed a significant main effect [$F_{(3, 612)} = 3.84$, $p = 0.0097$]. Furthermore, a significant interaction was found between the hindsight-foresight manipulation and the detail-level scenario pairings [$F_{(3, 612)} = 2.72$, $p < 0.0437$]. The significance of this interaction was due to the differences in the cubic terms between hindsight and foresight manipulations [$F_{1, 204)} = 5.08$, $p < 0.0252$]. The two groups did not differ in either the linear or the quadratic terms over time.

Comparisons of cell means were conducted using Ryan's procedure. It was revealed that within the hindsight condition, the HL and HH scenario pairings were statistically significantly different from LL and LH pairings. No other differences were statistically significant (see Figure 4). This indicates the hindsight group showed an increase in likelihood judgments as the level of detail increased within the actual scenario. The foresight group shows no change in likelihood judgments across detail-level pairings.

Alternative Outcomes. For the alternative outcomes, a hindsight bias would be indicated by a significantly lower likelihood judgment than under the foresight condition (i.e., underestimation of the likelihood of the alternative scenarios). A 2 (hindsight, foresight) X 4 (detail-level scenario pairing: HL, HH, LL, LH) split-plot factorial ANOVA was performed. The hindsight-foresight manipulation was the between subjects factor and detail-level pairings was the within-subject factor.

The hindsight-foresight manipulation revealed a significant main effect [$F_{(1, 204)} = 35.58$, $p < 0.0001$]. The hindsight group produced significantly lower likelihood judgments than the foresight group. This result indicated that a hindsight bias was also produced for the alternative scenarios (see Figure 5).

The detail-level pairing manipulation revealed a significant main effect [$F_{(3, 612)} = 6.35$, $p = 0.0003$]. Further, a significant interaction was found between the hindsight-foresight manipulation and the detail-level pairings ($F_{(3, 612)} = 2.82$, $p < 0.0384$). The significance of this interaction was due to the differences in the cubic terms between hindsight and foresight manipulations [$F_{1, 204)} = 7.25$, $p < 0.0077$]. The two groups did not differ in either the linear or the quadratic terms over time.

Examination of the cell means using Ryan's procedure revealed that within the hindsight group the likelihood judgment for the HL pairing was significantly smaller than the HH, LL or LH scenario pairings. The HH pairing was not significantly different from the LL pairing. The LH pairing was significantly larger than all the other detail-level scenario pairings. Further, the LH pairing was not significantly different from the foresight group. The foresight group showed no change in likelihood judgments across detail-level pairings.

Categorical data. The results from the "actual" outcome scenario were not quite as predicted. It was predicted that as the level of detail in the alternative outcome increased, the hindsight bias for the actual outcome would be reduced. This did not happen. In fact, the level of detail in the alternative outcome did not appear to affect likelihood judgments for the actual outcome.

For this reason it was decided to convert the likelihood judgments to categorical data, and to examine which outcome scenario (actual versus alternative) received the highest likelihood more frequently.

Data were converted into three categories: the "actual" outcome scenario received the highest likelihood, the alternative received the highest likelihood, or both were judged equally likely. A 3 (higher rated category: actual, alternative, equally likely) X 4 (detail-level scenario pairing: HL, HH, LL, LH) chi-square analysis was performed. It was found that fewer details in the "actual" outcome scenario led more individuals to rate the alternative outcome as more probable than or equal to the actual outcome.

The Pearson chi- square statistic provided evidence of an association between detail-level scenario pairing and category ($X^2_{(6, 456)} = 60.29$, $p < 0.0001$). See Table 2. The cell chi-square values showed that most of the association is due to the HL and LH scenario pairings. For the HL pairing, more people judged the actual outcome scenario ($X^2 = 4.6955$, *deviation from expected* = 20.5) as more likely than expected, and less people judged the alternative outcome scenario more likely than expected ($X^2 = 14.81$, *deviation from expected* = -15.75). The opposite occurs with the LH condition where most of the association is due to more people than expected judging the alternative scenario as most likely (X^2 = *19.884, deviation from expected* = 18.25*)* and fewer people than expected judging the actual scenario as most likely (X^2 = *7.74, deviation from expected* = -12.5*).*

Discussion

The foresight group shows no change in likelihood judgments across detail-level. Thus, in the absence of outcome knowledge, the participants' judgments were virtually the same no matter how the actual and alternative scenarios were paired. In fact, the cell means ranged from a minimum of 50.26 to a maximum of 54.97.

However, when given outcome knowledge a hindsight bias was committed for both the "actual" and "alternative" scenarios. Participants judged the likelihood of the "actual" scenario to be greater under the hindsight condition than the foresight condition. Likewise, a hindsight bias for the alternative scenarios was indicated by a reduced likelihood judgment than under the foresight condition.

The specificity of the probe had an effect on likelihood judgment when given outcome knowledge. Participants judged more detailed outcome scenarios as more likely than less detailed ones. Further, asymmetrical probing appeared to make a difference for the alternative outcomes. When the "actual" scenario was high, and the alternative outcome was sketchy, the hindsight bias was exaggerated for the alternative outcomes. Even more interesting was that when the level of detail for the "actual" scenario was sketchy, and the alternative scenario was high, the foresight and hindsight groups were not significantly different. Thus, at least for the alternative scenarios the hindsight bias appears to have been eliminated.

At first, asymmetrical probing did not appear to have the same effect on the actual outcome judgments. The amount of detail in the alternative outcome scenario did not affect the likelihood judgments for the actual outcome. This result led to an examination of the categorical data. It was found that more participants judged the "actual" outcome scenario to be more likely under the HL scenario pairing than expected, and more than expected judged the alternative outcome scenario more likely under the LH scenario pairing. This does fit the predicted pattern.

One reason that the asymmetrical probing might have had a clearer effect on the alternative outcome is that biases for these judgments are not quite as extreme. Hindsight effect for alternative outcomes have been shown in other research to produce smaller effects and to stay closer to the participants' original estimates (Fischhoff, 1977; Fischhoff & Beyth, 1975; Woods, 1978). Another possible reason the asymmetrical probing results were not as strong as predicted could be that the asymmetry may not have been extreme enough.

Comparison to MINERVA-DM predictions. A comparison of Experiment 1 likelihood judgments and MINERVA-DM predictions is presented in Figure 6. The top curve corresponds to the actual scenario outcome judgments and the bottom curve corresponds to judgments for alternative scenarios. Two MINERVA-DM simulations were run. In one simulation, G was set to 0.4 to simulate when the actual outcome was highly detailed and the alternative was not. The second simulation set G to 0.8 to both probes having relatively high details. There were 1000 simulated participants and the learning parameter was set to 0.75. The model's predictions showed the same decrease as participants' estimates. This indicates that as G increases the level of detail in the actual and alternative scenarios becomes more similar, and the magnitude of the bias is reduced. This is what was found in Experiment 1. Thus, a greater asymmetry in the amount of details used to probe memory leads to a greater feelings of certainty for what actually happened and reduced feelings of certainty for what did not.

Experiment 2

In this experiment, the amount of details in the probe will be manipulated through differential forgetting. It was predicted that more details for alternative outcomes would be forgotten over time than details for "what actually happened." Conversely, a greater number of details for "what actually happened" should be retained in LTM. This would naturally create an asymmetry in the probes, and therefore, magnify the hindsight bias.

Furthermore, while vignettes are useful in studying the hindsight bias, the technique is artificial. A real world task would provide a stronger test of the explanation than a vignette paradigm, and would be more generalizable to settings under which the hindsight bias naturally occurs. Finally, fewer empirical studies have explored hindsight bias for real-world events.

One example of the use of a real-world event to study the hindsight bias is Fischhoff and Beyth (1975). They asked students to estimate the likelihood that the United States would establish a diplomatic mission in Peking, that President Nixon would meet Mao at least once, and so on. Two weeks to six months after the trips took place, the students were asked to recall what their earlier probability estimates had been, and to indicate which outcome(s) had in fact occurred. Fischhoff and Beyth (1975) found that the hindsight bias became more prevalent when the initial predictions preceded the recall task by several months (3 to 6 months). For example, 84 percent of the students committed a hindsight bias when three to six months separated the recall task from actual event as opposed to 75% at 2 weeks.

In the current experiment, two University of Oklahoma football games were used for real-world events. Previous research has also used sporting events to mimic more realistic conditions under which the bias could be tested (Bond-Raacke et al., 2001; Leary, 1981), and were able to demonstrate a hindsight bias. In this experiment, participants who watched a football game were asked to make a hypothetical judgment about how they would have answered if they had not known the actual outcome of the game.

A general knowledge test was developed and used to assess participants' knowledge of the football game, and knowledge of the University of Oklahoma football team. This test was developed in order to screen for individuals with at least novice-level knowledge. It was also used to determine if an individual's knowledge level would influence his/her memory for the game.

Lastly, this study manipulated the length of time between the initial event and the probability judgments. It was hypothesized that the probability judgments for "what actually happened" would become more extreme as the time interval increased (See Figure 7). Furthermore, it was predicted that over time the number of details remembered by participants would decrease for both "what actually happened" and "what might have happened but did not" (the alternative outcome). However, fewer details for the actual[3] outcome would be lost during the delay between the first and second phase of the experiment. More details for alternative outcomes would be lost as time passes (see Figure 8).

Method

Participants. Participants (n = 59) were recruited from the psychology student subject pool at the University of Oklahoma. Only participants who would be watching the particular football games (either live in the stadium or on TV) were recruited. Participants who merely planned to listen to the game on the radio were not recruited in order to keep the medium under which individuals experienced the game as similar as possible. Further, it was reasoned that individuals who merely listened to the game may not pay as close attention as those who watched. Participants were tested in groups of up to 15 people.

Participants were assigned to one of three groups: 1) a foresight group (n = 18) who made likelihood judgments about an

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[3] Here "actual" outcome refers to who actually won the game.

upcoming football game in absence of outcome knowledge; 2) a hindsight group (n = 22) that returned two days after watching the game, and 3) a hindsight group (n =19) that returned after six days. To reduce attrition between first and second phases of the experiment, a $20.00 drawing took place during the second phase. In fact, no participants were lost to attrition. The experiment did not extend beyond a 6-day period because it was believed that watching the next week's football game would interfere with the memory test—memories for more recent games might weigh too heavily in LTM memory.

Materials and Stimuli. Participants were asked to complete a general knowledge quiz about football and the football team at the University of Oklahoma. After unsuccessful attempts to locate a general knowledge football quiz, one was developed to screen for basic novice-level football knowledge (Appendix B). Several sources of football rules and information were used to develop the test. These included *Football for Dummies* (Long & Czarnecki, 1998), the *Official 1999 NCAA Football Rule Book*, and the website www.football.com. The test consisted of 15 multiple-choice general knowledge questions about the game (e.g., How many yards are there on a football field? How many players per team can be on the field during a play? What is the tight end position?), and five multiple choice questions about the Sooner football team (e.g., Who is the head coach? Who is the current starting quarterback?). This resulted in a total of 20 questions. The test questions were selected on the basis of a pretest carried out on 15 participants. From the set of pretest questions, only questions which 2/3 of the participants had answered correctly were selected.

The two football games (Oklahoma vs. Texas A & M and Oklahoma vs. Oklahoma State University) used in this experiment were chosen for two reasons: 1) they both were home games 2) they were both broadcast on live TV in Norman, Oklahoma, and 3) both were Saturday games. Also, it should be noted that the previous year was a losing season for the Oklahoma football team (5 wins to 6 losses) and that the Sooners had lost to both opposing teams used in the experiment. Furthermore, both games were preceded by a loss in the current season. Therefore, it was believed that participants would entertain the possibility that their home team could lose to the challengers.

A true/false memory test was developed immediately following each football game: the University of Oklahoma vs. Texas A & M, and University of Oklahoma vs. Oklahoma State University. Each memory test contained 10 true statements that supported an OU win (THOME), 10 true statements that were supportive of the opposing team winning (TOPP), 10 false statements that were favorable towards the OU team (FHOME), and 10 false statements that were favorable to the opposition (FOPP). See Table 3 for examples of statements.

The author and two assistants independently watched the game and took detailed notes on events that occurred throughout the game. Furthermore, the game was recorded and the sports sections from all local papers were collected the following day in order to provide an independent means to verify the memorable events. A memorable event was selected for a "true" statement only if all three developers: 1) listed the event in their notes, 2) were in agreement on the event being highly memorable, and 3) were in agreement on whether the event was favorable for the Home Team or favorable for the opposition. The false statements were selected from a set of statements created by the test developers. Again, a statement was selected only if 1) the event never occurred during the game and 2) all three developers were in agreement on the event favoring Home Team or the opponent.

Procedure. The first phase of the experiment took place on the Friday before the football game. During this phase, all participants took the general football knowledge quiz. The foresight group then proceeded to make likelihood predictions for the upcoming Oklahoma football game. Participants in the hindsight groups were then reminded to watch the football game. They were then asked to return either two or six days after the game.

Hindsight participants were asked to keep a detailed journal of all the times they thought about, discussed, listened to (e.g., TV, radio, etc.) anything concerning the game, the team, the coaches, and so on between the first phase of the experiment and the second. The diary was used to determine if participants revisited their memories of the game they watched, and if so, how often. Also, it was important to determine if the longer delay condition resulted in more revisiting.

During the second phase of the experiment, the memory diaries were collected. Participants then took the memory test concerning the game and rated the likelihood of OU winning or losing the game. Participants were asked to make the likelihood judgments as if they had not watched the game and did not know the final outcome. The memory test and likelihood judgments were counterbalanced across participants to eliminate order effects. At the end of the session, participants were asked to recall: 1) who won the game, and 2) what was the final score.

Results

General Information. Three participants were removed from the data set before analyses were conducted—two from the 2-day group and one from 6-day group. These individuals scored less than 50% on the general knowledge test, and less than 45% on the memory test. This indicated that these individuals had little knowledge of the game of football, and that they actually scored worse than guessing (50%) on the memory test. This resulted in a final total of 56 participants: 18 participants in the foresight condition, 20 in the 2-day condition and 18 in the 6-day condition.

Twenty-six participants watched the game live on their television sets and 12 watched it live in the stadium. No significant difference ($X^2_{(1, 38)} = 0.228$, $p = 0.63$) was found between the 2-day group (13 TV, 7 stadium) and the 6-day group (13 TV, 5 stadium). Furthermore, where they watched had no significant effect on the participants' likelihood judgments.

Finally, all participants (100%) remembered who won the game (OU won both games used in the experiment). Twenty-eight individuals accurately remembered the score and 10 did not. However, no significant difference ($X^2_{(1, 38)} = 2.79$, $p = 0.095$) was found between the 2-day group (3 forgot, 17 remembered) and the 6-day group (7 forgot, 11 remembered).

General Football Knowledge. The three experimental groups (foresight, 2-day, and 6-day) were not significantly different from each other in their knowledge of the game and home team. The mean knowledge score was 79.26% (SD = 11.3). Scores ranged from 53% to 100%. Thus, the three groups were equally knowledgeable about the game of football and the OU team. Knowledge scores were found to be unrelated to likelihood scores.

Hindsight Bias. To determine if a hindsight bias had occurred, two separate one-factor (experimental conditions: foresight, 2-day, and 6-day) ANOVAs were conducted on likelihood judgments: one for the probability of the home team (Sooners) winning, and one for the probability of losing.

For the probability of winning, the three conditions were found to be significantly different from each other ($F_{(2, 53)} = 13.01$, $p < 0.0001$). Ryan's multiple comparison procedure was used to determine any differences between the means. The foresight, 2-, and 6-day conditions differed significantly from each other in winning likelihood judgment. Thus, a bias was found for both hindsight conditions, and further, this bias was found to significantly increase between the 2-day and 6-day delays (see Figure 9).

A significant difference was found for likelihood of losing judgments across experimental conditions ($F_{(2, 53)} = 6.43$, $p = 0.003$). Here the foresight group and the 6-day group differed significantly from each other. No other difference was significant (see Figure 9).

Memory. The 2-day and 6-day groups did not differ from each other on overall memory scores ($t_{(36)} = 1.56$, $p = 0.064$). The mean memory score was 65.8% (SD = 9.09). The range was 53 to 85% correct.

Next, the subsections of the memory test were examined separately. See Table 4 for a comparison of the mean scores for each subsection across experimental conditions. THOME, FHOME, and FOPP subsections of the test did not differ across the hindsight conditions. However, the 2-day hindsight condition (M = 71%, SD = 23.09) was significantly better than ($t_{(36)} = 2.34$, $p = 0.03$) the 6-day hindsight condition (M = 51.39%, SD 21.45) for the TOPP subsection. See Figure 10. This meant that while memories for items favoring the home team winning did not differ across time, memory for items favoring the opponent winning did. These details were forgotten at a faster rate. Thus, details favoring alternative outcomes were forgotten at a much higher rate.

Correlations. No significant relation was found between participant's likelihood judgments and the overall memory test score. However, a significant, negative relation was found between the subsection for true statements concerning the opponent (TOPP) and likelihood judgments. The more accurate the participants' memory for events favorable to the opponent, the lower the likelihood judgment for winning (r = -0.6, $p < 0.0001$). Further, a significant, positive relation was found between memory for true items favoring the opposition and the likelihood of losing. The more accurate memory for events favoring the opponent, the greater the judged likelihood of losing (r = 0.55, p = 0.0003). These two correlations accounted for 36% and 30% of the variation in the likelihood judgments respectively. No other significant relation was found for the subsections of the memory test.

To summarize, these findings indicated that it was not so much what these participants remembered, but what they forgot that affected their judgments. Memories for information supporting the winning team were virtually the same for the 2-day and 6-day groups. However, true information about the opposition started out at the same level as true statements for the home team at 2-days, but then dropped (or faded) significantly by six days. The change in the likelihood judgments was related to this loss of memories for information favoring the opponent.

Diaries. One individual in the 6-day hindsight group did not turn in a diary. This individual was allowed to complete the second phase of the experiment, but was not entered into the $20 drawing. Also, another diary from the 6-day group was found to be unacceptable. It contained only entries of a personal nature, and none concerning the game. Therefore, this diary was excluded from the analysis. Thus, a total of 36 diaries were analyzed (16 for the 6-day, and 20 for the 2-day).

First, the diary entries were subdivided into "revisiting" units – entries that clearly indicated the participant spent time thinking about and remembering the football game. Participants naturally provided discrete intervals between entries in the diaries. Next, a coding scheme was developed to classify the idea units. Five major and 10 minor categories were developed. See Table 5 for a list of the categories and a brief description. Note that many dairy entries consisted merely of a statement remembering to record an entry (i.e., nothing today, just remembered to make an entry). The author assumed that even this would trigger some revisiting of the game, even if only cursory. Thus, these entries were coded. Using the coding scheme the author and an associate coded each diary unit. Differences in coding were resolved through discussion. Coders only disagreed on three (3) out of 307 entries. The overall agreement was 99.02%, kappa 0.9835, $z = 27.7882$, $p < 0.0001$.

It was decided to focus on the five main categories and to determine the percentage of entries that fell into each category. Figure 11 gives the percentage of entries falling into each category for the 2-day and 6-day. The only main category in which the two conditions differed significantly ($t_{(34)} = -3.22$, $p = 0.003$) was in the proportion of journaling entries. The 6-day journaling comprised an average of 20.56 % of the entries as opposed to 5.63% for the 2-day condition. For both hindsight conditions, only one subcategory got above 7%; watching TV (19.02% for 2-day, 16.84% for 6-day).

The total number of entries per participant was also examined. The 6-day condition had significantly ($t_{(34)} = -4.76$, $p < 0.0001$) more dairy entries (M = 11.19, SD = 3.71) than the 2-day condition (M = 6.4, SD = 2.28). Though this is not surprising it does show that the 6-day delay group did revisit events from the game. This may explain why the THOME memories did not differ across the 2-day and 6-day delays.

Discussion

To reiterate, participants' memories for events that favored the home team did not differ over time, but favorable memories for the opponent did. Over time the number of details remembered by participants decreased for the alternative outcome (the home team losing). However, memory for details of the actual outcome barely changed.

The fact that the participants revisited the game often may indicate why there was no difference in the memory scores for events favoring the Home Team. Revisiting the memories may have reinstantiated those memories, making them less susceptible to forgetting. Furthermore, considering that all the subjects were OU students and fans, they probably did not revisit as frequently information that was positive for the opponent. In fact, out of the 307 total entries, only one was negative towards the Home Team and there were no positive references toward the opposition. Almost all entries were congratulatory in some way (e.g., we discussed how great it was to beat Texas A & M).

These results demonstrated that there was differential forgetting of the details for the "actual" outcome versus what might have happened, but did not. Also, probability judgments became more extreme as the asymmetry in the details remembered increased. Thus, differential forgetting may be one of the factors contributing to the differences in the probes, and may be one of the reasons the hindsight bias becomes more extreme over time.

Comparison to MINERVA-DM Predictions. As in Experiment 1, two MINERVA-DM simulations were performed. In the first simulation, G was set to 0.4. This simulates a situation where the probe for the actual outcome scenario is highly detailed and the probe for what did not occur has relatively few details. In the second simulation, G was set to 0.8, and simulates situations where both probes (what actually happened and what did not) have relatively high levels of details. There were 1000 simulated participants; the Learning parameter was set to 0.75.

Figure 12 shows a comparison between MINERVA-DM predictions and the results from Experiment 2. The top line corresponds to the judgments concerning the actual outcome (the home team winning) and the bottom line corresponds to the judgments for the alternative outcome (the home team losing). The model predictions have the same functional form as the results from Experiment 2. However, the likelihood judgments for Experiment 2 were more extreme than MINERVA-DM predicted. That may have been because the home team won both games by a large margin, and thus, may have been more memorable than most games.

In conclusion, when the level of detail is less similar between the actual outcome and the alternative outcome the magnitude of the bias is greater. As in Experiment 1, a greater asymmetry in the amount of details used to probe memory led to a greater feeling of certainty for what actually happened. Finally, differential forgetting of details results in a greater asymmetry; thus, increasing the magnitude of the hindsight bias over time.

General Discussion

The research reported in this paper demonstrates that the amount of detail used to probe LTM influences the magnitude of the hindsight bias. As the level of detail increased for an outcome, so did its judged probability. When the outcome was "what actually happened," this led to an excessive feeling of certainty; thus producing the hindsight bias. However, for alternative outcomes the hindsight bias was reduced by increasing the details in its probe. Because the hindsight bias for alternatives is expressed in terms of excessive feelings of improbability, an increase in feelings of certainty reduces its bias.

Furthermore, asymmetrical probing of LTM (i.e., using one probe that is highly detailed, and one that is sketchy) exaggerated these effects. When the probe for the actual event was highly detailed and the alternative was sketchy, it led to an even more extreme feelings of certainty for what actually happened, and reduced feelings of certainty for what might have happened but did not. In other words, it magnified the effects of the hindsight bias for both outcomes.

This type of detail-level pairing of outcomes most closely matches the natural circumstances under which the hindsight bias occurs. Under ordinary circumstances, people are provided with few details concerning the alternatives. For example, the media rarely give a balanced picture with equal time and details for alternative scenarios. In fact, most details for "what might have happened, but did not" are internally generated; and internally generated memories are naturally less detailed than real ones (Johnson & Raye, 1981).

Even more remarkable though is the fact that the hindsight bias for the alternative scenarios was eliminated when the level of detail for the alternative scenario was high and the actual scenario was sketchy. Under these conditions, the foresight and hindsight judgments for the alternative scenario contained similar levels of certainty. However, the hindsight bias for what actually happened was merely reduced by increasing the amount of details in the alternative outcome; it was not eliminated. This speaks to the robustness and tenacity of this bias. Biases for actual events are more extreme and thus, it may require a vast amount of details regarding the alternatives to eliminate them. Further, it is much easier to make judgments about the occurrence of an event than to make judgments about how unlikely an event is to occur.

Factors that Contribute Details. In the current studies, three factors contributed to the different levels of details in the probes. First, the level of detail was provided by the experimenter's decision task (Experiment 1) via the vignettes. Second, different rates of forgetting (Experiment 2) coupled with the revisiting of certain old memories resulted in varying levels of detail. Revisiting the memories may have reinstantiated the memories; making them less susceptible to forgetting. Over time details for the alternative scenarios will fade faster than details for the actual scenario.

A third possible factor for contributing details to the probe is false memories. Real world decision tasks require an individual to discriminate between different sources of information, and his/her memory for source is often imperfect (Johnson et al, 1993). Further, no memory is based purely on externally generated information; all memory traces have some degree of cognitive elaboration (Johnson & Raye, 1981). Revisiting these memories (e.g., watching ESPN or discussing the game with friends) may have allowed the participants to develop false memories for the game. Thus, false memories could play some role in inflating the level of certainty by adding false details to the probes.

In Experiment 2, errors of commission may have played a role in producing the hindsight bias for the 2-day delay condition. For this group, equal numbers of details concerning the game were remembered for both outcome scenarios (actual versus alternative scenarios; winning versus losing). However, participants made considerably more errors of accepting false statements favoring the home team winning as true, as opposed to false statements favoring the opposition. Participants accepted 68% of false statements favoring the home team, and only 33% of those favoring the opposition. These false memories may have boosted the level of detail for a win.

Over time more false memories for "what actually happened" might be generated, thus creating more details that could be used to probe memory. Future researchers should attempt to address the issue of the use of detailed memories and false memories in the hindsight bias with other circumstances.

Alternative Explanations. There are a few alternative explanations for the results demonstrated in this paper. One explanation is that traces for "what actually occurs" are better encoded into LTM than those for the alternatives. Another explanation entails a greater number of traces in LTM for "what actually happened" as opposed to "what might have happened but did not". In other words, the probes are not different for what actually happened versus what might have happened. Instead, the traces in LTM match the probe better, because they are more detailed and more abundant.

MINERVA-DM simulations were run varying the learning parameter, and the number of traces stored in LTM. From these simulations, MINERVA-DM predicts that if the level of detail is held relatively the same for both outcomes probes (G = 0.8), better encoding or increasing memory traces gives the actual outcome only a slightly higher probability. In other words, both could produce a bias, but their effect would be minimal compared to varying the level of detail in the probes. It should be noted that MINERVA-DM does predict that when there is a disparity in the amount of details in the probe, better encoding and large numbers of traces further exaggerate the hindsight bias.

Empirical evidence validates MINERVA-DM's explanations, and backs up the results from the current research. First, the hindsight bias is smaller for easier questions as opposed to harder ones (Hawkins & Hastie, 1990). Easier questions are better encoded, and information concerning such questions is believed to be more frequent in memory. Further, experts have been shown to exhibit smaller and slightly less excessive hindsight biases than laypersons (Christensen-Szalanski & Wilham, 1991; Pohl, 1992). In fact, Pohl (1992) did not find any differences between experts and laypersons as far as the hindsight bias is concerned. Thus, expertise neither eliminates nor enhances the bias. A greater amount of knowledge (larger number of traces) and better encoding of relevant information are characteristic of expert decision makers (Shanteau, 1988). If encoding and a greater number of traces were to have an affect on the hindsight bias, one would expect experts to have exaggerated effects, and not be similar to laypersons.

The current research, also, provides evidence to counter the alternative explanations. For example, the depth of encoding was similar for both the actual outcome and the alternative in Experiment 2. The 2-day delay participants remembered equal amounts of details for the actual outcome (Home team wins) as for the alternative (opposition wins). Furthermore, in Experiment 1 participants were exposed to both the actual and alternative outcomes only once. Therefore, the number of traces placed in long-term memory was similar for both outcome scenarios.

However, one could not rule out the possibility that Experiment 2 participants laid down new traces in LTM while revisiting memories for the game. These new traces would tend be biased towards the actual outcome, since no diary entries concerned the alternative outcome. Furthermore, these traces could subsequently used to access similar traces in LTM, and further boost the feelings of certainty

More Alternatives Versus a More Detailed Alternative. MINERVA-DM predicts that it is not whether alternative scenarios are used to probe memory, but rather the level of detail contained in these probes. In other words, it is not the number of alternatives that an individual generates, but rather it is the degree of detail in the alternative probe that causes a reduction in the hindsight bias. In fact, Sanna, Schwartz, and Stocker (2002) found that listing many counterfactual thoughts was experienced as difficult, and consistently increased the hindsight bias for what participants believed was the "actual" outcome. Thus, generating more alternatives did not lessen the bias, but instead made the alternatives seem less likely because they were so hard to produce. This mechanism is similar to Tversky and Kahneman (1973) availability bias.

Generating more details for an alternative may work better than generating more alternative probes, because what is contained within the probe shapes the reconstruction of the likelihood judgment (Hawkins & Hastie, 1990; Pohl, Eisenhauer, & Hardt, 2003; Schwartz & Stahlberg, 2003). The reconstruction process involves searching LTM for evidence relevant to the task. The probe influences the reconstruction process, by selectively increasing access to information in memory that is consistent with the probe. Next, the evidence is evaluated, weighted and recombined to produce an overall judgment (Hawkins & Hastie, 1990). The probes could bias the memory search towards information relevant to what actually happened (biased sampling) by ignoring details concerning alternative scenarios. Asking individuals to generate *detailed* alternative scenarios may lead these individuals to decrease the likelihood of the outcome they believe occurred by increasing the probe's access to more traces in LTM.

Conclusion

People's tendency to overestimate the accuracy with which they could predict past events occurs quite frequently in the real world. MINERVA-DM provides a new explanation for the cognitive processes that underlie the hindsight bias. It may also provide ideas for new techniques to debias individuals, such as having an individual generate a very detailed description of a single alternative outcome.

The research in this paper lends support to MINERVA-DM as a coherent and integrative theory for likelihood judgments. MINERVA-DM provides a theoretical framework in which to conduct future judgment and decision making research. Future success would indicate that there may be just a few overarching cognitive mechanisms that cause the various heuristics and biases studied by decision researchers. Already, MINERVA-DM has been used to account for heuristics and biases such as the availability bias (Dougherty & Franco-Watkins, 2003), overconfidence (Dougherty, 2001), as well as conditional judgments, representiveness, base-rate neglect, the conjunction effect and so on (see Dougherty, Gettys & Ogden, 1999 for a more comprehensive list). MINERVA-DM provides an exciting theoretical framework in which to examine how these heuristics and biases are related, and to understand the relation between them.

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Appendix A

MINERVA-DM Simulation Program. The program was written originally by Charles F. Gettys.

```
uses CRT, TURBO3, Default;
Const
 SlotsInField = 9;
 ElementsInVector = 3 * SlotsInField; {Each trace vector has 27
     elements.
                         9 Ds, 9 Hs, and 9 Cs}
                        {Note order of mini-vectors is D,H,C}
 MaxHyps  = 10;
 MaxData  = 10;
 MaxRandomArray = 27;
 MinTraceType = 3; {Determines min. number of -1, 0, +1 values
     in vector}
 SlotsInProbe : byte = MinTraceType * 9;
 Debug : boolean = false{true};
 RevisedOn = '9/25/96';
```

```
type
  RandomArray = array[1..ElementsinVector] of shortint;
  CharSet = set of char;
var
  ProbeArr   : array[1..MaxData, 1..MaxHyps, 1..ElementsInVector]
of shortint;
  TraceArr  : RandomArray; {The Trace array}
  FreqHandD : array[1..MaxData, 1..MaxHyps] of word; {f(H&D)
array}
  Intensity : array[1..MaxData, 1..MaxHyps] of real;
  SumIntensity : array[1..MaxData, 1..MaxHyps] of real;
  Similarity : array[1..MaxData, 1..MaxHyps] of real;
  EchoContent: array[1..MaxData, 1..MaxHyps,
1..ElementsInVector] of real;
  SumSim : array[1..MaxData, 1..MaxHyps] of real;
  NSum : array[1..MaxData, 1..MaxHyps] of longint;
  RndArr : RandomArray;
  RndArr2 : RandomArray;
  i, j : word;
```

NumHyps : byte; {number of hypotheses}

NumDs : byte; {number of data}

L : real; {Hintzman's learning rate parameter}

TracesMade : word; {Traces created by the program}

NumberReps : word; {Number of trials in the simulation}

Params : text; {Parameter file containing last values used}

TypeSim : char; {Specifies type of simulation wanted}

Conjunction: char; {Specifies type of conjunction effect wanted}

HCrit : real; {critical value of H for No Base rate search}

Context : char; {Specifies that contextual cues will be used (y or n)}

Experimental : char; {Specifies if it is experimental, or non-exp context}

NumContexts: byte; {specifies number of contexts used: 0=none, 1=many}

ChangeL : char; {if 'Y' changes L to study avalability}

NumCorrect : longint; {Count of number of correct inferences made by M3}

NumWrong : longint; {count of incorrect inferences}

LValidity : real; {value of L for validity effect routine. Suggest >=.9}

```
  NumTrActive: byte; {Number of traces that will have high value of
L}
  TrActive : byte; {Temporary variable for NumTrActive}
  GrandSumI,
  GrandSumS : real; {Sums used in summary}
  NumExtras : word; {Number of extra-experimental context
vectors}
  Ch : char;
  ID : string[80]; {ID string to better indentify procedures}

procedure WaitForKey;
var
  Ch : char;
  Xpos, Ypos : byte;

begin
  Xpos := wherex;  Ypos := wherey;
  write('Press any key except d to go on, press d to turn off
debuging.');
  repeat until keypressed;
```

```
  Ch := readkey;
  gotoxy(Xpos,Ypos);
  clreol;
  if (Ch = 'd') or (Ch = 'D') then Debug := false;
end;


procedure Delay(Time:word);
var
  i, j :word;
begin
  for i := 1 to Time do J := j;
end;


procedure Rearrange(var RandomVector: RandomArray;
          MinValue, MaxValue: integer);
          {randomizes using sampling without replacement}
var
 i, RandomPick, SwapValue : integer;
begin
  {randomize;}
```

```
  for i := MaxValue downto MinValue do
   begin
    RandomPick := Random(i-MinValue) + MinValue + 1;
    {write(randomPick:5);}
    SwapValue := RandomVector[i];
    RandomVector[i] := RandomVector[RandomPick];
    RandomVector[RandomPick] := SwapValue;
   end;
end;

procedure title; {Title display for DPL programs}
 var
  Sp : string[12];
  Ch : char;
  begin
   Sp := chr(13)+chr(10)+'          ';
   writeln(sp,'Title: MINERVA3');
   writeln(sp,'Author: Chuck Gettys');
   writeln(sp,'Date Created: 11/7/95');
```

```
  writeln(sp,'Comments: Modification to MINERVA2 to deal with
likelihoods.');
     if paramcount = 0 then
       begin
         repeat until keypressed;
         Ch := readkey;
         clrscr;
       end;
 end;

procedure GetVariables; {Allows the user to specify variables}
var
 H, D : byte;
 PromptStr : string;
begin
  Conjunction:=CharDefault('Conjunction effect[use with H&D
only,H>=3,D=1]:(Y-Yes,N-No)?',
                           Conjunction, ['Y', 'N']);
  TypeSim := CharDefault('Analysis Wanted:(F-Freq, B-H&D, L-
L(D|H), P-L(H|D), C-Cond.)?',
```

```
                    TypeSim, ['F', 'B', 'L', 'P', 'C']);
 TypeSim := CharDefault('More Choices: (E-Echo,S-Hsight,X-
Expert,V-Validity,H-Hintz.)?',
                    TypeSim,['E', 'S', 'X', 'V', 'H']);
 if TypeSim = 'V' then
   begin
     LValidity := RealDefault('L for activated traces wanted (Suggest
L>=.9)?', LValidity);
     NumTrActive := ByteDefault('Number of active traces
wanted?',NumTrActive);
   end;
 Context := CharDefault('Context effects wanted: (Y- yes, N- no)',
                    Context, ['Y', 'N']);
 ChangeL := CharDefault('Changes in L with H wanted (for
availability): (Y- yes, N- no)',
                    ChangeL, ['Y', 'N']);
 NumberReps := WordDefault('Number of trials in the simulation?',
NumberReps);
 L := RealDefault('Learning rate parameter?', L);
```

```
  HCrit := RealDefault('S criterion for H. (Range -1.0 to +1.0) ?',
HCrit);
  {PS := realDefault('Probe similarity. Range: 0 to + 1 ?', PS);}
  NumHyps := ByteDefault('Number of Hypotheses?', NumHyps);
  NumDs := ByteDefault('Number of data?', NumDs);
  writeln;
  writeln('Now you will enter the frequencies of H and D:');
  for H := 1 to NumHyps do
    for D := 1 to NumDs do
      begin
        PromptStr := 'HandD('+ chr(48+H) + ',' + chr(48+D) + ') (0-
65,535) = ? ';
        FreqHandD[H,D] := WordDefault(PromptStr,
FreqHandD[H,D]);
      end;
  NumExtras := WordDefault('Num.  extra exp. context (0-65,535)?',
NumExtras);
end;

procedure CreateVector;
```

```
var
  i, NumsInMiniVector : byte;
begin
 NumsInMiniVector := 3 * MinTraceType;
 for i := 1 to MinTraceType do
   begin
     RndArr[i] := -1;
     RndArr[i+MinTraceType] := 0;
     RndArr[i+2*MinTraceType] := 1;
   end;
 Rearrange(RndArr, 1, NumsInMiniVector);
end;


procedure BuildProbes;
const
  NumsInMiniVector = 3 * MinTraceType;
var
 i, j, k, H, D : byte;
 Ch : char;
 HMiniVector : array[1..MaxHyps,1..NumsInMiniVector] of shortint;
```

```
DMiniVector : array[1..MaxData,1..NumsInMiniVector] of shortint;

begin
 for i := 1 to NumHyps do
  begin
   CreateVector; {Make H vector}
   for j := 1 to NumsInMiniVector do
     HMiniVector[i,j] := RndArr[j];
  end;
 for i := 1 to NumDs do
  begin
   CreateVector; {Make D vector}
   for j := 1 to NumsInMiniVector do
     DMiniVector[i,j] := RndArr[j];
  end;
 CreateVector; {Make C vector}
 for D := 1 to NumDs do
  for H := 1 to NumHyps do
   for i := 1 to NumsInMiniVector do
    begin
```

```
      ProbeArr[D,H,i] := DMiniVector[D,i];
      ProbeArr[D,H,i+NumsInMiniVector] := HMiniVector[H,i];
      ProbeArr[D,H,i+2 * NumsInMiniVector] := RndArr[i];
    end; {Now, even for H=1, there is an unique D component. A
change!}
 if Debug then
   begin
     writeln('Output of BuildProbes. Probe vectors generated:');
     writeln('D# H#  Data part          Hypothesis part     Context
part');
     for j := 1 to NumDs do
       for k := 1 to NumHyps do
         begin
           write(j:2, k:2, '  ');
           for i := 1 to 3 * NumsInMiniVector do
             begin
               write(ProbeArr[j, k, i]:2);
               if (i = 9) or (i = 18) then write('  ');
             end;
             writeln;
```

```
        end;
        WaitForKey;
    end;
end;


procedure CreateTrace(D,H: byte; Context, Experimental : char);
{creates a single trace according to specifications supplied}
var
  Slot, EndSlot : byte;
  LTemp : real;
begin
  {Experimental := 'Y';} {Temp only}
  if Context = 'Y' then  EndSlot := 27 else EndSlot := 18;
  for Slot := 1 to EndSlot do
    TraceArr[Slot] := ProbeArr[D,H,Slot];
  if not (Context='Y') then
    for Slot := 19 to 27 do
      TraceArr[Slot] := 0;
  if (Conjunction = 'Y') and (TypeSim = 'B') and (H<3) then
    for Slot :=  1 to 9
```

```
    do TraceArr[Slot] := 0; {Conjuction fallacy. H should be >= 3!!!!}
  if (Context = 'Y') and (not (Experimental= 'Y')) then
   Rearrange(TraceArr, 19,27);
   if ChangeL <> 'Y' then
    begin
     if (TypeSim = 'V') and (TrActive > 0) then
      begin
       Ltemp := L;
       L := LValidity * 1000;
      end;
     for Slot := 1 to EndSlot do
      if random(1000) > L then TraceArr[Slot] := 0; {L fixed cond.}
     if (TypeSim = 'V') and (TrActive > 0) then
      begin
       L := LTemp;
       if TrActive > 0 then dec(TrActive);
      end;
    end
     else
      for Slot := 1 to EndSlot do {L variable cond.}
```

```
        if random(1000) > (L * H) then TraceArr[Slot] := 0;
  if Debug then
   begin
    writeln('Current TraceArray (D part, H part, C part):');
    write(D:2,H:2,Context:2,Experimental:2, '   ');
    for Slot := 1 to 27 do
     begin
      write(TraceArr[Slot]:2);
      if (Slot = 9) or (Slot = 18) then write('  ');
     end;
    writeln;
    WaitForKey;
   end;
end;

Function CalcSim(D, H : byte; Context : Char; StartCalc, EndCalc:
byte) : real;
var
  i, j, N : byte;
  SumProduct : real;
```

```
begin
 SumProduct := 0.0;
 N := 0;
 for i := StartCalc to EndCalc do
  begin
   SumProduct := SumProduct + ProbeArr[D,H,i] * TraceArr[i];
   if (not (ProbeArr[D,H,i]=0)) or (not (TraceArr[i]=0)) then inc(N);
  end;
 if Debug then
  begin
   writeln('CalcSim vector products=', SumProduct:8:3, '    N=',
N:3);
   WaitForKey;
  end;
 if N > 0 then CalcSim := SumProduct/N
  else
   CalcSim := 0;
end;
```

```
Function CalcEchoSim(D, H:byte; Context: Char; StartCalc,
EndCalc:byte):real;
var
 i, j, N : byte;
 SumProduct : real;
begin
 SumProduct := 0.0;
 N := 0;
 for i := StartCalc to EndCalc do
  begin
   SumProduct := SumProduct
    + ProbeArr[D,H,i] * EchoContent[D, H, i];
   if (not (ProbeArr[D,H,i]=0)) or (not (EchoContent[D, H, i]=0))
    then inc(N);
  end;
 if Debug then
  begin
   writeln('CalcSim vector products=', SumProduct:8:3, '    N=',
N:3);
   WaitForKey;
```

```
  end;
 if N > 0 then CalcEchoSim := SumProduct/N
  else
    CalcEchoSim := 0;
end;

procedure DoFreq; {Frequency estimation simulation routine}
var
 D,H, NumD, NumH, StartCalc, EndCalc, NumCon, LastCon :
byte;
 FHandD, LastFreq: word;
 S, S3  : real; {Hintzman's similarity}
 Ch : char;

begin
 if Context = 'Y' then
    EndCalc := 27;
    LastCon := 1;
  end
   else
```

```
begin
  EndCalc := 18;
  LastCon := 0;
end;
StartCalc := 10; {Do similarity starting at slot 10 to ignore
        'data' mini-vector}
for NumCon := 0 to LastCon do
  for H := 1 to NumHyps do
    for D := 1 to NumDs do
      begin
        if NumCon = 0 then LastFreq := FreqHandD[H,D]
         else
           LastFreq := NumExtras div (NumHyps * NumDs); {Note: a
slight error may be introduced here because of integer division. Fix
is to make sure (NumHyps * NumDs) is an exact mutiple of
NumExtras.}
        for FHandD := 1 to LastFreq do
          begin
            if NumCon = 0 then
              CreateTrace(D,H,Context,'Y')
```

```
            else
              CreateTrace(D,NumHyps,Context, 'N');{all non-exp
contexts dumped H3}
          for NumD := 1 to NumDs do
            for NumH := 1 to NumHyps do
              begin
                S := CalcSim(NumD,NumH, Context, StartCalc,
EndCalc);
               SumSim[NumD,NumH] := SumSim[NumD,NumH] + S;
                SumIntensity[NumD,NumH] :=
                  SumIntensity[NumD,NumH] + S * S * S;
                if Debug then
                  begin
                    S3 := S * S * S;
                    writeln('D=',NumD:2, '  H=',NumH:2, '  S=',S:8:3,
                           '  S Cubed=', S3:8:3);
                    WaitForKey;
                  end;
              end;
          end;
```

```
    end;
end;

procedure DoHandD; {Conjuction simulation routine}
var
 D,H, NumD, NumH, StartCalc, EndCalc, NumCon, LastCon :
byte;
 FHandD, LastFreq: word;
 S, S3  : real; {Hintzman's similarity}
 Ch : char;

begin
 if Context = 'Y' then
  begin
   EndCalc := 27;
   LastCon := 1;
  end
   else
    begin
     EndCalc := 18;
```

```
        LastCon := 0;
      end;
  StartCalc := 1; {Do similarity starting at slot 1}
  for NumCon := 0 to LastCon do
    for H := 1 to NumHyps do
      for D := 1 to NumDs do
        begin
          if NumCon = 0 then LastFreq := FreqHandD[H,D]
           else
             LastFreq := NumExtras div (NumHyps * NumDs); {Note: a
light error may be introduced here because of integer division. Fix
is to make sure (NumHyps * NumDs) is an exact mutiple of
NumExtras.}

          for FHandD := 1 to LastFreq do
            begin
              if NumCon = 0 then
                begin
                 if TypeSim = 'S' then CreateTrace(1,1,Context,'Y')
                   else
```

```
            CreateTrace(D,H,Context,'Y');
            end
          else
           CreateTrace(D,NumHyps,Context, 'N');{all non-exp
contexts dumped H3}
        for NumD := 1 to NumDs do
         for NumH := 1 to NumHyps do


            S := CalcSim(NumD,NumH, Context, StartCalc,
     EndCalc);
           SumSim[NumD,NumH] := SumSim[NumD,NumH] + S;
            SumIntensity[NumD,NumH] :=
             SumIntensity[NumD,NumH] + S * S * S;
            if Debug then
             begin
              S3 := S * S * S;
              writeln('D=',NumD:2, '  H=',NumH:2, '  S=',S:8:3,
                  '  S Cubed=', S3:8:3);
              WaitForKey;
             end;
```

```
            end;
         end;
      end;
end;

procedure DoDGivenH; {minerva3 calculation for
representativeness}
var
  D,H, NumD, NumH, StartCalc, EndCalc : byte;
  FHandD  : word;
  S : real; {Hintzman's similarity}
  Ch : char;

begin
  StartCalc := 10; {Do similarity starting at slot 10}
  if Context = 'Y' then EndCalc := 27 else EndCalc := 18;
    for H := 1 to NumHyps do
      for D := 1 to NumDs do
        for FHandD := 1 to FreqHandD[H,D] do
          begin
```

```
          CreateTrace(D,H,Context,'Y');
          for NumD := 1 to NumDs do
            for NumH := 1 to NumHyps do
              begin
                S := CalcSim(NumD,NumH, Context, StartCalc,
EndCalc);
                if S >= HCrit then  {similarity of H and C exceeds HCrit}
                  begin
                   inc(NSum[NumD,NumH]); {So MEAN similarity can
be calculated}
                 S := CalcSim(NumD,NumH,Context,1,9); {Calculate D}
                 SumSim[NumD,NumH] := SumSim[NumD,NumH] + S;
                   SumIntensity[NumD,NumH] :=
                     SumIntensity[NumD,NumH] + S * S * S;
                  end;
                if Debug then
                  begin
                   writeln('D=',NumD:2, '  H=',NumH:2, '  S=',S:8:3);
                   WaitForKey;
                  end;
```

```
            end;
        end;
end;

procedure DoHGivenD; {Does P(H|D) minerva3 calculation}

var
 D,H, NumD, NumH, StartCalc, EndCalc : byte;
 FHandD : word;
 S : real; {Hintzman's similarity}
 Ch  : char;

begin
 StartCalc := 10; {Do similarity starting at slot 10}
 if Context = 'Y' then EndCalc := 27 else EndCalc := 18;
  for H := 1 to NumHyps do
   for D := 1 to NumDs do
    for FHandD := 1 to FreqHandD[H,D] do
     begin
      CreateTrace(D,H,Context,'Y');
```

```
for NumD := 1 to NumDs do
  for NumH := 1 to NumHyps do
    begin
      S := CalcSim(NumD,NumH, Context, 1, 9);
      if Debug then
        begin
          writeln('Conditional:  D=',D:2,'  H=',H:2,'
DP=',NumD:2, '  HP=',NumH:2, '  S=',S:8:3);
          WaitForKey;
        end;
      if S >= HCrit then  {similarity of D and C exceeds HCrit}
        begin
          inc(NSum[NumD,NumH]); {So MEAN similarity can
be calculated}
          S := CalcSim(NumD,NumH,Context,10,18);
{Calculate H}
         SumSim[NumD,NumH] := SumSim[NumD,NumH] + S;
          SumIntensity[NumD,NumH] :=
            SumIntensity[NumD,NumH] + S * S * S;
          if Debug then
```

```
                begin
                  writeln('NonCond:      D=',D:2,'  H=',H:2,'
DP=',NumD:2,
                  '  HP=',NumH:2,  '  S=',S:8:3);
                  WaitForKey;
                end;
            end;
        end;
    end;
end;

procedure ZeroEchoArr;
var
  i, j, k : byte;
begin
  for i := 1 to NumDs do
    for j := 1 to NumHyps do
      for k := 1 to 27 do
        EchoContent[i, j, k] := 0.0
end;
```

```
procedure DoEcho; {Echo content calculation routine}
var
  D,H, NumD, NumH, StartCalc, EndCalc, NumCon, LastCon, Slot :
byte;
  FHandD, LastFreq: word;
  S, Activation   : real; {Hintzman's similarity}
  Ch : char;

begin
  ZeroEchoArr;
  if Context = 'Y' then
    begin
      EndCalc := 27;
      LastCon := 1;
    end
     else
      begin
        EndCalc := 18;
        LastCon := 0;
      end;
```

```
StartCalc := 1; {Do similarity starting at slot 1}
for NumCon := 0 to LastCon do
 for H := 1 to NumHyps do
  for D := 1 to NumDs do
   begin
    if NumCon = 0 then LastFreq := FreqHandD[H,D]
     else
      LastFreq := NumExtras div (NumHyps * NumDs); {Note: a
slight error may be introduced here because of integer division. Fix
is to make sure (NumHyps * NumDs) is an exact mutiple of
NumExtras.}
    for FHandD := 1 to LastFreq do
     begin
      if NumCon = 0 then
       CreateTrace(D,H,Context,'Y')
        else
         CreateTrace(D,NumHyps,Context, 'N');{all non-exp
contexts dumped H3}
      for NumD := 1 to NumDs do
       for NumH := 1 to NumHyps do
```

```
begin
 S := CalcSim(NumD,NumH, Context, StartCalc,
EndCalc);{Eq1}
 SumSim[NumD,NumH] := SumSim[NumD,NumH] + S;
 Activation := S * S * S;   {Equation 2}
 for Slot := 1 to EndCalc do
   EchoContent[NumD, NumH, Slot] :=
     EchoContent[NumD, NumH, Slot]
       + Activation * TraceArr[Slot];  {Equation 4}
 if Debug then
   begin
     writeln('D=',NumD:2, '  H=',NumH:2, '  S=',S:8:3);
     if TypeSim = 'E' then
       begin
         writeln('Preliminary Echo Content calculations:');
         for Slot := 1 to Endcalc do
           writeln('Slot=', Slot:3,'   EcCon=',
             EchoContent[NumD, NumH, Slot]:12:3,
             '  Act=',Activation:12:3, '   TrArr=',
               TraceArr[Slot]:3);
```

```
                    end;
                  WaitForKey;
                end;
              end;
           end;
         end;
 for H := 1 to NumHyps do
  for D := 1 to NumDs do
   begin
    S := CalcEchoSim(D,H, Context, StartCalc, EndCalc);
    SumSim[D,H] := SumSim[D,H] + S;
    SumIntensity[D,H] :=
     SumIntensity[D,H] + S * S * S;
   end;
end;


procedure ZeroSummary;
var
 i,j, Slot : byte;
begin
```

```
 for i := 1 to NumDs do
  for j := 1 to NumHyps do
    begin
     if (TypeSim = 'L') or (TypeSim = 'P') then NSum[i,j] := 0
      else
        NSum[i,j] := 1;
     SumIntensity[i,j] := 0.0;
     SumSim[i,j] := 0.0;
     if TypeSim = 'E' then
       for Slot := 1 to 27 do
         EchoContent[i,j,Slot] := 0.0;
    end;
end;


Procedure ShowSummary;
var
 i,j : byte;


begin
 GrandSumI := 0;
```

```
GrandSumS := 0;
for i := 1 to NumDs do
  for j := 1 to NumHyps do
    begin
      SumSim[i,j] := SumSim[i,j]/(NumberReps*NSum[i,j]);
      GrandSumS := GrandSumS + SumSim[i,j];
      SumIntensity[i,j] :=
SumIntensity[i,j]/(NumberReps*NSum[i,j]);
      GrandSumI := GrandSumI + SumIntensity[i,j];
    end;
writeln('Last Revised: ', RevisedOn);
writeln(ID);
writeln('     ');
writeln('  D  H','Mean I':14, 'I(D^H)':10, 'Mean S':10, 'S(H^D)':10);
for i := 1 to NumDs do
  for j := 1 to NumHyps do
    writeln(i:3, j:3, SumIntensity[i,j]:14:3,
(SumIntensity[i,j]/GrandSumI):10:4,
    SumSim[i,j]:10:4, (SumSim[i,j]/GrandSumS):10:4 );
if NumCorrect <> 0 then
```

```
  begin
    writeln('Note: above matrix is based on one rep only,
disregard!!!');
    writeln('Correct inferences: ', NumCorrect, '  Incorrect: ',
NumWrong,
       '  P(C)= ', (NumCorrect/(NumCorrect+NumWrong)):6:3);
  end;
 {Calculate M(D|H) values also by normalizing down columns}
end;


procedure SaveParams;
var
 H, D : byte;
begin
 assign(Params, 'minerva3.val');
 rewrite(Params);
 writeln(Params, Conjunction);
 writeln(Params, TypeSim);
 writeln(Params, Context);
 writeln(Params, ChangeL);
```

```
  writeln(Params, NumberReps);
  writeln(Params, L/1000.0);
  writeln(Params, HCrit);
  writeln(Params, NumHyps);
  writeln(Params, NumDs);
  for H := 1 to NumHyps do
    for D := 1 to NumDs do
      writeln(Params, FreqHandD[H,D]);
  writeln(Params, NumExtras);
  close(Params);
end;

procedure InitializeVariables;
var
  H, D  : byte;
begin
  Conjunction := 'N';
  TypeSim := 'B';
  Context := 'N';
  if Context = 'Y' then NumContexts := 1
```

```
  else
    NumContexts := 0;
  ChangeL := 'N';
  NumberReps := 100;
  L := 1.0;
  {PS := 1.0;}
  HCrit := -1.0;
  NumHyps := 2;
  NumDs := 2;
  for H := 1 to NumHyps do
    for D := 1 to NumDs do
      FreqHandD[D,H] := 25;
  NumExtras := 0;
  NumCorrect := 0;
  NumWrong := 0;
  LValidity := 0.95;
  NumTrActive := 1;
end;

procedure GetParams;
```

```
var
  H, D : byte;
  OK : boolean;
begin
  assign(Params, 'minerva3.val');
  {$i-}reset(Params); {$i+}
  OK := (IOresult = 0);
  if not OK then exit;
  readln(Params, Conjunction);
  readln(Params, TypeSim);
  readln(Params, Context);
  readln(params, ChangeL);
  readln(Params, NumberReps);
  readln(Params, L);
  readln(Params, HCrit);
  readln(Params, NumHyps);
  readln(Params, NumDs);
  for H := 1 to NumHyps do
    for D := 1 to NumDs do
      readln(Params, FreqHandD[H,D]);
```

```
  readln(Params, NumExtras);
  close(Params);
end;

procedure SaveData;
var
  DataOut : text;
  H, D, I : word;

begin
  assign(DataOut, 'minerva3.dat');
  {$I-}append(DataOut); {$I+}
  if ioresult <> 0 then rewrite(DataOut);
  writeln(DataOut);
  writeln(DataOut);
  writeln(DataOut,'Minerva3 output. Last Revised: ', RevisedOn);
  writeln(DataOut,'Value supplied to conjuction switch: ',
Conjunction);
  writeln(DataOut,'Type Simulation: ', TypeSim);
  writeln(DataOut,ID);
```

```
 if TypeSim = 'V' then
   begin
     writeln(DataOut, 'Value of L for validity effect routine: ',
LValidity);
     writeln(DataOut, 'Number of traces that had a high value of L:
',NumTrActive);
   end;
 if TypeSim = 'S' then
    writeln(DataOut,'D=1,H=1 corresponds to scenario active in
memory');
 writeln(DataOut,'Context Used: ', Context);
 writeln(DataOut,'L changed: ', ChangeL);
 writeln(DataOut,'Number of trials: ', NumberReps);
 writeln(DataOut,'L= ', (L/1000.0):4:2);
 writeln(DataOut,'H Critical value: ', HCrit:4:2);
 writeln(DataOut,'Number Hypotheses: ', NumHyps);
 writeln(DataOut,'Number Data: ', NumDs);
 for H := 1 to NumHyps do
   for D := 1 to NumDs do
     writeln(DataOut,'f(',H:2,',',D:2,')= ', FreqHandD[H,D]);
```

```
 writeln(DataOut, 'Number extra exp. contexts: ', NumExtras);
 writeln(DataOut,'     ');
 writeln(DataOut,' H D','Mean I':12, 'I(D^H)':10, 'Mean S':10,
'S(H^D)':10);
 for i := 1 to NumDs do
   for j := 1 to NumHyps do
     writeln(DataOut,j:2, i:2,'   ',SumIntensity[i,j]:10:4,
(SumIntensity[i,j]/GrandSumI):10:4,
       SumSim[i,j]:10:4, (SumSim[i,j]/GrandSumS):10:4 );
 if NumCorrect <> 0 then
   begin
     writeln(DataOut,'Note: above matrix is based on one rep. only,
disregard!!!');
     writeln(DataOut,'Correct inferences: ', NumCorrect, '  Incorrect:
', NumWrong,
        '  P(C)= ', (NumCorrect/(NumCorrect+NumWrong)):6:3);
   end;

 close(DataOut);
end;
```

```
procedure GetCmdLineParams;
var
  Code, H, D, j : word;
  Temp : string;
begin
  Temp := paramstr(1);
  TypeSim := Temp[1]; {picks off first char of a string}
  Temp := paramstr(2);
  Context := Temp[1];
  Temp := paramstr(3);
  ChangeL := Temp[1];
  val(paramstr(4), NumberReps, Code);
  val(paramstr(5), L, Code);
  val(paramstr(6), HCrit, Code);
  val(paramstr(7), NumHyps, Code);
  val(paramstr(8), NumDs, Code);
  if NumHyps * NumDs > 12 then
    begin
      writeln('Too many command line arguments (ie. H * D > 12).');
```

```
      writeln('halting program');
      halt;
    end;
  j := 8;
  for H := 1 to NumHyps do
    for D := 1 to NumDs do
      begin
        inc(j);
        val(paramstr(j), FreqHandD[H,D], Code);
      end;
end;

procedure DoExpert; {procedure to examine growth of expertise}
var
i, j : byte;

begin
  DoHgivenD;
  {ShowSummary;}
  if SumIntensity[1,1] > SumIntensity[1,2] then inc(NumCorrect)
```

```
    else inc(NumWrong);
  if SumIntensity[2,2] > SumIntensity[2,1] then inc(NumCorrect)
    else inc(NumWrong);
  {writeln('Correct: ', NumCorrect:4, '    wrong: ', NumWrong);}
  {WaitForKey;}
  if (NumCorrect+NumWrong)>= NumberReps then exit;
  for i := 1 to NumDs do
    for j := 1 to NumHyps do
      begin
        SumSim[i,j] := 0.0;
        SumIntensity[i,j] := 0.0;
        {GrandSumI := 0.0;}
      end;
end;


procedure DoValidity;
begin
  TrActive := NumTrActive;
  DoHGivenD;
end;
```

```
procedure DoConditional;
var
  D,H, NumD, NumH, StartCalc, EndCalc : byte;
  FHandD        : word;
  S             : real; {Hintzman's similarity}
  Ch            : char;

begin
  StartCalc := 10; {Do similarity starting at slot 10}
  if Context = 'Y' then EndCalc := 27 else EndCalc := 18;
    for H := 1 to NumHyps do
      for D := 1 to NumDs do
        for FHandD := 1 to FreqHandD[H,D] do
          begin
            CreateTrace(D,H,Context,'Y');
            for NumD := 1 to NumDs do
              for NumH := 1 to NumHyps do
                begin
```

```
            S := CalcSim(NumD,NumH, Context, StartCalc,
EndCalc);
            if S >= HCrit then  {similarity of H and C exceeds HCrit}
             begin
              {inc(NSum[NumD,NumH]);} {So MEAN similarity can
be calculated}
              S := CalcSim(NumD,NumH,Context,1,EndCalc);
{Calculate D}
             SumSim[NumD,NumH] := SumSim[NumD,NumH] + S;
              SumIntensity[NumD,NumH] :=
               SumIntensity[NumD,NumH] + S * S * S;
             end;
            if Debug then
             begin
              writeln('D=',NumD:2, '  H=',NumH:2, '  S=',S:8:3);
              WaitForKey;
             end;
          end;
      end;
end;
```

```
procedure DoHintzman;
var
  D,H, NumD, NumH, StartCalc, EndCalc, NumCon, LastCon, Slot :
byte;
  FHandD, LastFreq: word;
  S, Activation   : real; {Hintzman's similarity}
  Ch : char;

begin
  ZeroEchoArr;
  if Context = 'Y' then
    begin
      EndCalc := 27;
      LastCon := 1;
    end
     else
       begin
         EndCalc := 18;
         LastCon := 0;
```

```
    end;
  StartCalc := 9; {Do similarity starting at slot 9 to get D vector
only}
  for NumCon := 0 to LastCon do
    for H := 1 to NumHyps do
      for D := 1 to NumDs do
        begin
          if NumCon = 0 then LastFreq := FreqHandD[H,D]
           else
             LastFreq := NumExtras div (NumHyps * NumDs); {Note: a
slight error may be introduced here because of integer division. Fix
is to make sure (NumHyps * NumDs) is an exact mutiple of
NumExtras.}
          for FHandD := 1 to LastFreq do
            begin
              if NumCon = 0 then
                CreateTrace(D,H,Context,'Y')
                 else
                   CreateTrace(D,NumHyps,Context, 'N');{all non-exp
contexts dumped H3}
```

```
            for NumD := 1 to NumDs do
              for NumH := 1 to NumHyps do
                begin
                  S := CalcSim(NumD,NumH, Context, StartCalc,
EndCalc);{Eq1}
                SumSim[NumD,NumH] := SumSim[NumD,NumH] + S;
                  Activation := S * S * S;   {Equation 2}
                  for Slot := 1 to EndCalc do
                    EchoContent[NumD, NumH, Slot] :=
                      EchoContent[NumD, NumH, Slot]
                        + Activation * TraceArr[Slot];  {Equation 4}
                  if Debug then
                    begin
                      writeln('D=',NumD:2, '  H=',NumH:2, '  S=',S:8:3);
                      if TypeSim = 'E' then
                        begin
                          writeln('Preliminary Echo Content calculations:');
                          for Slot := 1 to Endcalc do
                            writeln('Slot=', Slot:3,'   EcCon=',
                              EchoContent[NumD, NumH, Slot]:12:3,
```

```
                        ' Act=',Activation:12:3, '  TrArr=',
                        TraceArr[Slot]:3);
                      end;
                    WaitForKey;
                  end;
                end;
            end;
          end;
 for H := 1 to NumHyps do
   for D := 1 to NumDs do
     begin
       S := CalcEchoSim(D,H, Context, 1, 8);
       SumSim[D,H] := SumSim[D,H] + S;
       SumIntensity[D,H] :=
         SumIntensity[D,H] + S * S * S;
     end;
end;

procedure MoreID; {Adds ID string to output to make reduce
errors}
```

```
var
begin
  case TypeSim of
    'F' : ID := 'Calc. on H mv., ignoring D. Can include context if
specified.';
    'B' : ID := 'CAlc. on H & D combined. Can include context if
specified';
    'L' : ID := 'Likelihood L(D|H) calculation. Does not do context.';
    'P' : ID := 'Posterior L(H|D) calculation. Does not do context.';
    'E' : ID := 'Hintzman''s echo content. Does context.';
    'S' : ID := 'Hindsight routine. one probe: "What happened", Does
context';
    'X' : ID := 'Expertise routine. Diddles L(H|D) proc. Limited,
requires stand. data input.';
    'V' : ID := 'Validity effect routine. Diddles L(H|D) proc.';
    'C' : ID := 'Experimental Bayesian analog. Shows base rates.
Uses context.';
    'H' : ID := 'Explores Hintzman''s suggestion involving echo
intensity. Uses context';
  end;
```

```
end;
begin {main block}
  clrscr;
  randomize; {Should be called ONCE only at the beginning}
  if paramcount <> 0 then lowvideo;
  Title;
  InitializeVariables; {Set variables to default values}
  GetParams; {from file on disk}
  if paramcount = 0 then GetVariables {From keyboard}
   else
     GetCmdLineParams;
  MoreID;
  L := 1000 * L;  {scale to range used by random}
  ZeroSummary;
  writeln;
  writeln('Pressing any key except d aborts program. D key toggles
debug.');
  gotoxy(1,wherey);
  for i := 1 to NumberReps do
    begin
```

```
if keypressed then
  begin
    Ch := readkey;
    if (Ch='d') or (ch='D') then Debug := true
      else
        exit;
  end;
if i mod 10 = 0 then write(i:4);
gotoxy(1,wherey);
BuildProbes;
case TypeSim of
  'F' : DoFreq;
  'B' : DoHandD;
  'L' : DoDGivenH;
  'P' : DoHGivenD;
  'E' : DoEcho;
  'S' : DoHandD;
  'X' : DoExpert;
  'V' : DoValidity;
  'C' : DoConditional;
```

```
      'H' : DoHintzman;
      {'I' : DoInstantiation;}
    end;
  end;
ShowSummary;
SaveParams; {to file on disk}
SaveData; {Save results to file Minerva3.dat}
if paramcount = 0 then repeat until keypressed;
NormVideo;
end.
```

Appendix B

Football Knowledge Quiz

1. How long is the football field?

a) 100 feet

b) 500 feet

c) 100 yards

d) I don't know

2. How long is a regulation football?

a) 6 to 6 ¼ inches

b) 11 to 11 ½ inches

c) 48 inches exactly

d) I don't know

3. Which of the following will stop the game clock?

a) The player holding the ball is out of bounds

b) The ball changes possession from one team to the other

c) The offense achieves a first down

d) All of the above

4. How many players per team can be on the field during a play?

a) 7

b) 9

c) 11

d) It depends on if you are the offense or the defense

5. How many points is a safety worth?

a) 1

b) 2

c) 3

d) 6

6. How many points is a touch back worth

a) 0

b) 1

c) 2

d) 3

7. Which statement describes the tight end position?

a) The player in this position is a combination of a lineman and a wide receiver.

b) A player who is lined up against the defense, and is closest to the ball before play begins.

c) This player is closest to the quarterback and either blocks incoming rushers or has the ball handed off to them.

d) I don't know

8. Which of the following will **NOT** stop a play?

a) when the ball carrier is grounded whether it be his own fault or a defender

b) when the ball carrier's feet touches the ground out of bounds

c) when a pass attempt is completed

d) when a foul is called by a referee

9. Before the two-minute warning, a time out lasts ___________; after the warning the time outs are only _______ long.

a) 2 minutes 30 seconds; 1 minute

b) 1 minute 50 seconds; 40 seconds

c) 1 minute 30 seconds; 30 seconds

d) 2 minutes; 2 minutes

10. Which of the following circumstances results in **ONLY** the loss of a down?

a) The ball was intentionally thrown backwards out of bounds

b) Forward pass touched by ineligible player in front of the neutral zone

c) Offensive pass interference

d) The ball was illegally handled when it was advanced

11. All of the following violations receive a 5-yard penalty **<u>EXCEPT</u>**:

a) Substitution rules are violated

b) A player crawls

c) Players communicating with the coach during an illegal time

d) All of the above receive a 5-yard penalty

12. Which of the following violations receives a 15-yard penalty?

a) Hurdling occurs

b) A team illegally calls a time out

c) A player is off sides

d) The ball is intentionally grounded

13. If a kick off or punt enters the end zone and is not returned, where does the opposing team get the ball?

a) 20 yard line

b) 50 yard line

c) From the point of the kick

d) 35 yard line

14. How many offensive players must line up on the line of scrimmage?

a) at least 5

b) 7 or more

c) 6 or less

d) There is no specific number

15. How many yards is considered the halo zone when receiving a kicked ball?

a) 1 yard

b) 5 yards

c) 2 yards

d) there is no halo zone

16. Who is the head coach for OU? Offensive coordinator? Defensive coordinator?

a) Stoops; Leach; Stoops & Venables

b) Simmons; Stoops; Venables

c) Stoops; Jackson; McBrown

d) Simmons; McCown; Beasley

17. Who did OU play last? What was the outcome?

a) Texas Tech; we lost

b) Iowa State University; we lost

c) TexasTech; we won

d) Iowa State University; we won

18. Who is the current starting quarterback for OU?

a) Applewhite

b) Thornton

c) Littrell

d) Heupel

19. Which of the following individuals is an OU receiver?

a) Savage

b) Heupel

c) Holleyman

d) Moore

20. Which of the following individuals is an OU linebacker?

a) Calmus

b) Heupel

c) Savage

d) Littrel

Figure 1.

Example of the effect of probe specificity on a vector representation of memory. The left side of the graph represents the effect of probing with a detailed probe (G = 1) and the right side represents probing memory with a less detailed probe (G = 0.5).

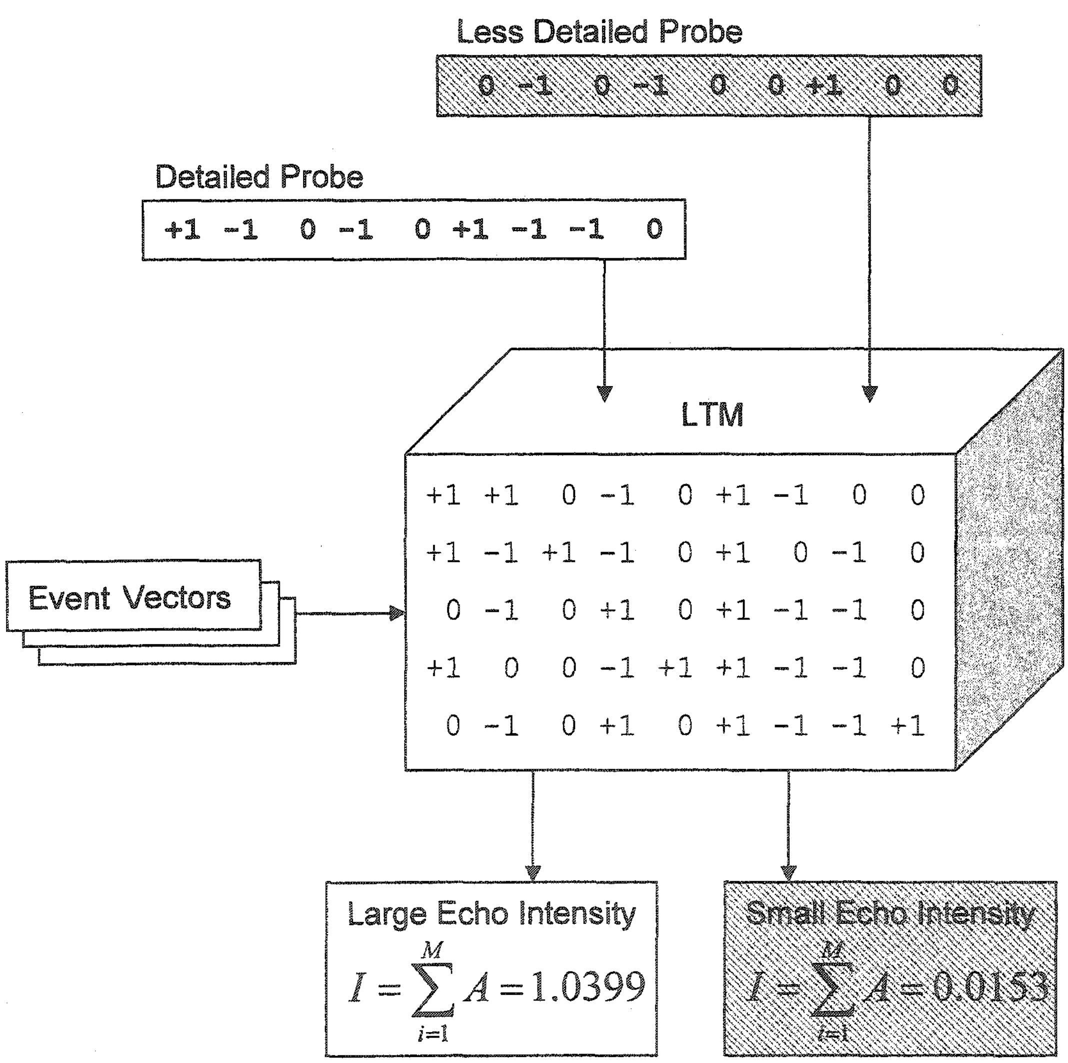

Figure 2.

The hindsight bias as simulated by MINERVA-DM. In the graph, the upper line is the likelihood (echo intensity) for the outcome that actually happened, and the lower line represents the likelihood for the alternative outcome.

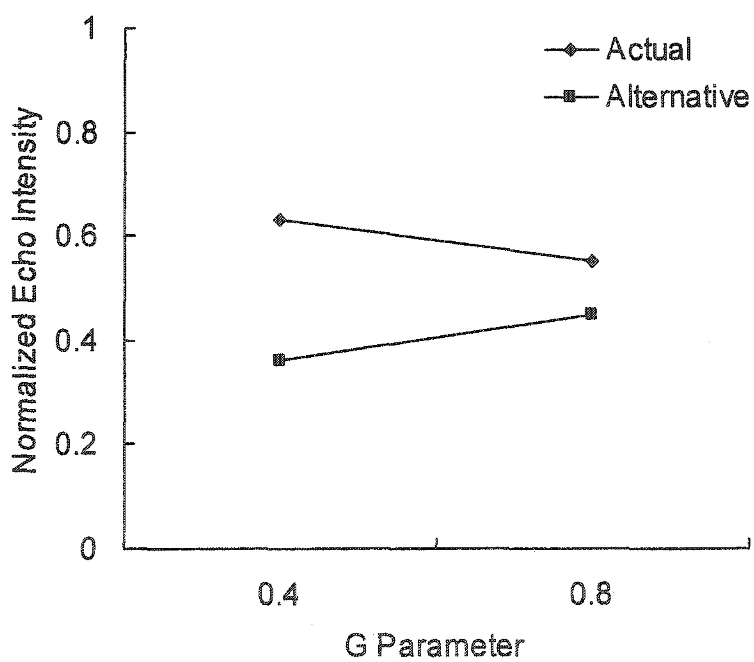

Figure 3.

Example of a Vignette and Possible Outcomes. For each patient vignette there were two possible diagnoses. For each diagnosis both a sketchy description and a detailed description were developed.

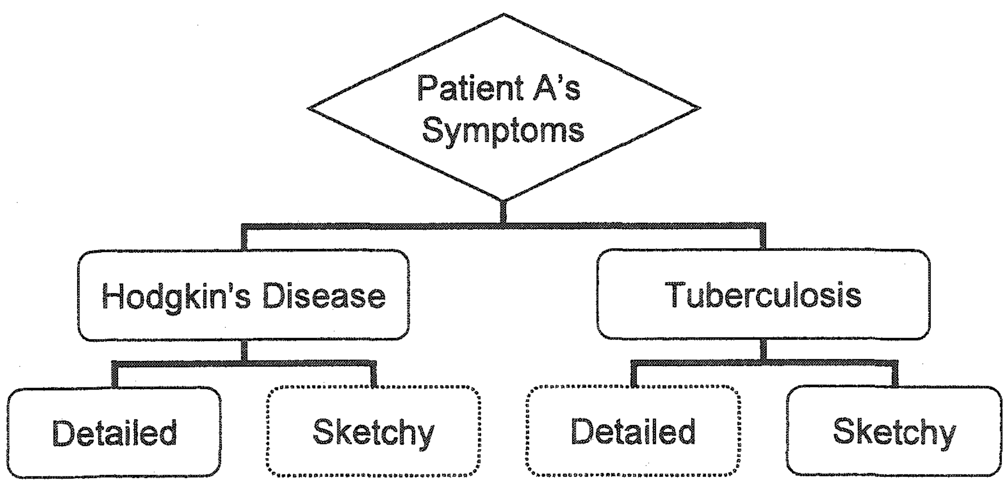

Table 1.

Summary of Possible Detail-Level Scenario Pairings. Participants read one vignette for each of the detail-level scenario pairings.

		Amount of Detail in Alternative Outcome	
		High	Low
Detail in Actual Outcome	High	HH	HL
	Low	LH	LL

Figure 4.

Actual Outcome. Likelihood judgments for the hindsight group were significantly higher than the foresight group. Within the hindsight group, highly-detailed outcome scenarios (HL, HH) were judged significantly more likely than those with fewer details. There was no difference in likelihood judgments within the foresight group.

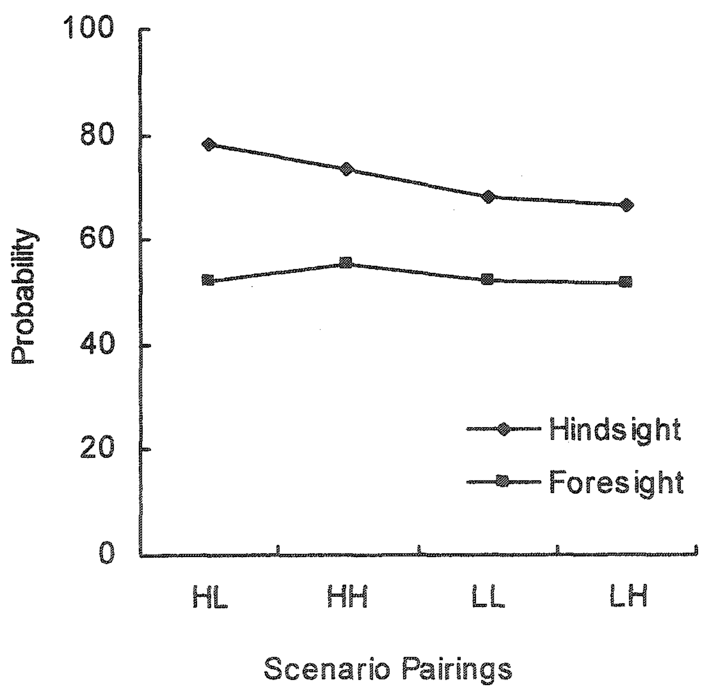

Figure 5.

Alternative Outcome. The hindsight group made significantly lower likelihood judgments than the foresight group. Within the hindsight group, the HL hindsight judgment was significantly lower than the other pairings. Finally, the LH judgment was not significantly different from the foresight group, thus, indicating that no hindsight bias occurred for this detail-level pairing.

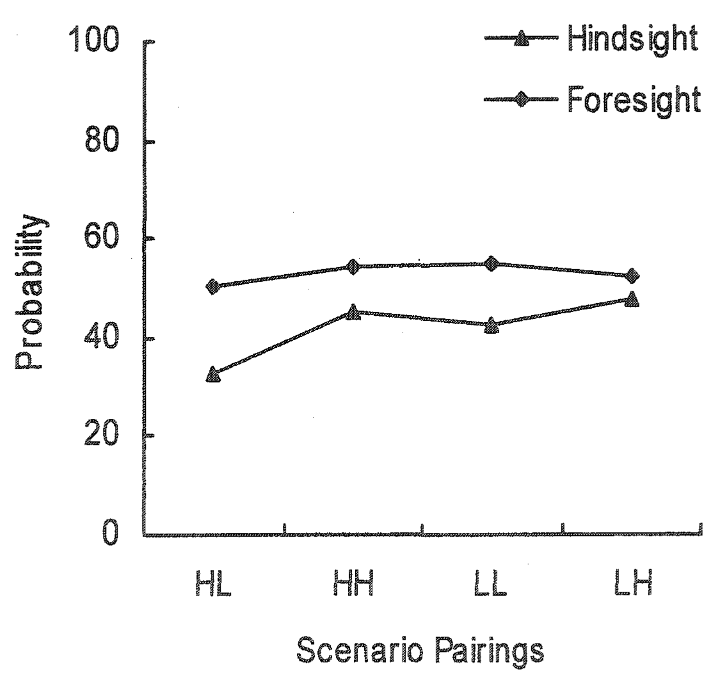

Table 2

Frequency Data for the Hindsight Condition. The likelihood judgments were categorized by which outcome was judged to be most probable.

Comparison	Judged Most Probable	Expected Frequency	Observed Frequency
HL	Actual	89.50	110
	Alternative	16.75	1
	Equal	7.25	3
HH	Actual	89.50	90
	Alternative	16.75	10
	Equal	7.25	14
LL	Actual	89.50	81
	Alternative	16.75	21
	Equal	7.25	12
LH	Actual	89.50	77
	Alternative	16.75	35
	Equal	7.25	2

Figure 6.

Likelihood judgments from Experiment 1 (top panel) and MINERVA-DM estimates (bottom panel). For both graphs, the upper line represents judgments for the actual outcome and the bottom line represents the alternative outcome.

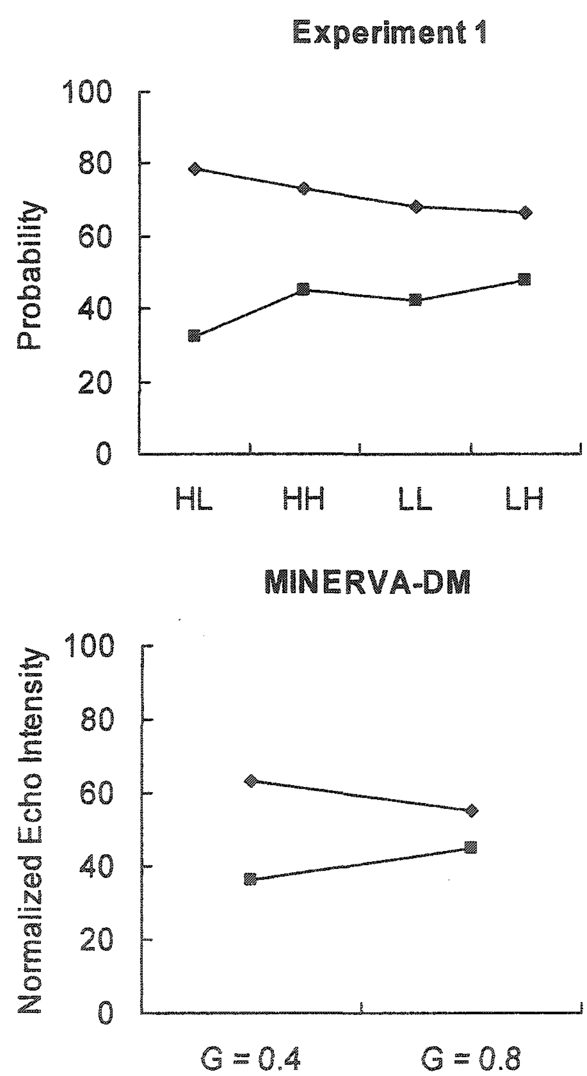

Figure 7.

The simulated effects of time on the hindsight bias. Probability judgments are predicted become more extreme as the delay increases between the event and the likelihood judgment.

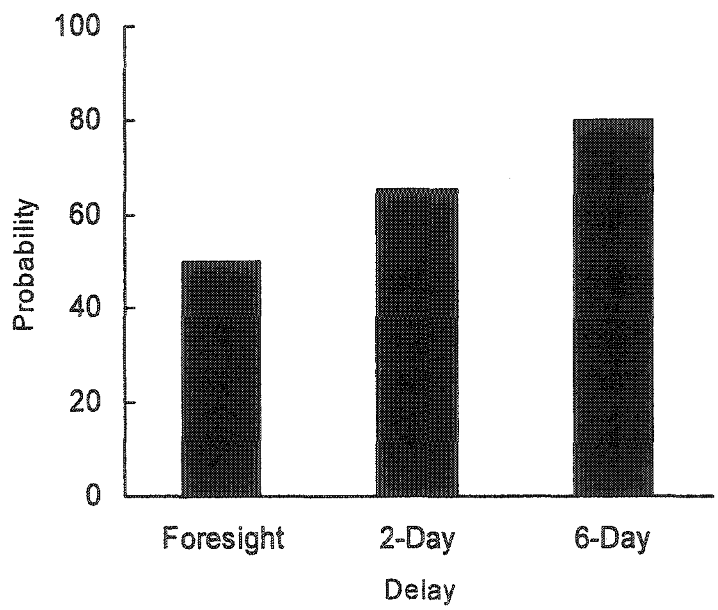

Figure 8.

Differential Forgetting. There would be a difference in the percentage of details remembered between the "actual" outcome scenarios, and the "alternative" outcomes over time.

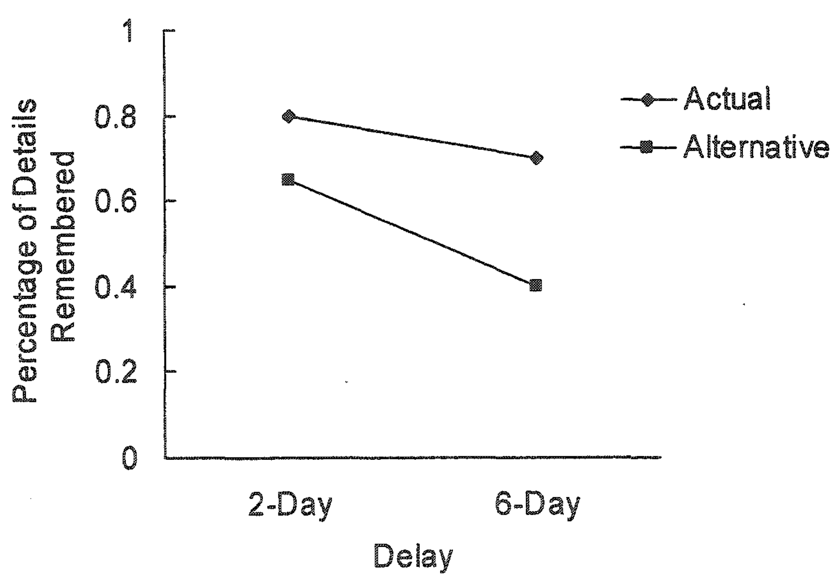

Table 3.

Example of Statements from the Memory Subtest

Type of Statement	Example
True favoring home team (THOME)	At the end of the first half, OSU threw a Hail Mary and OU intercepted it.
True favoring the opposition (TOPP)	During OU's first possession of the game, OSU recovered a fumbled ball.
False favoring home team (FHOME)	OU only punted one time during the entire game.
False favoring the opposition (FOPP)	Through out the game, OSU successfully batted away several of Heupel's passes.

Figure 9.

Likelihood Judgments Over Time

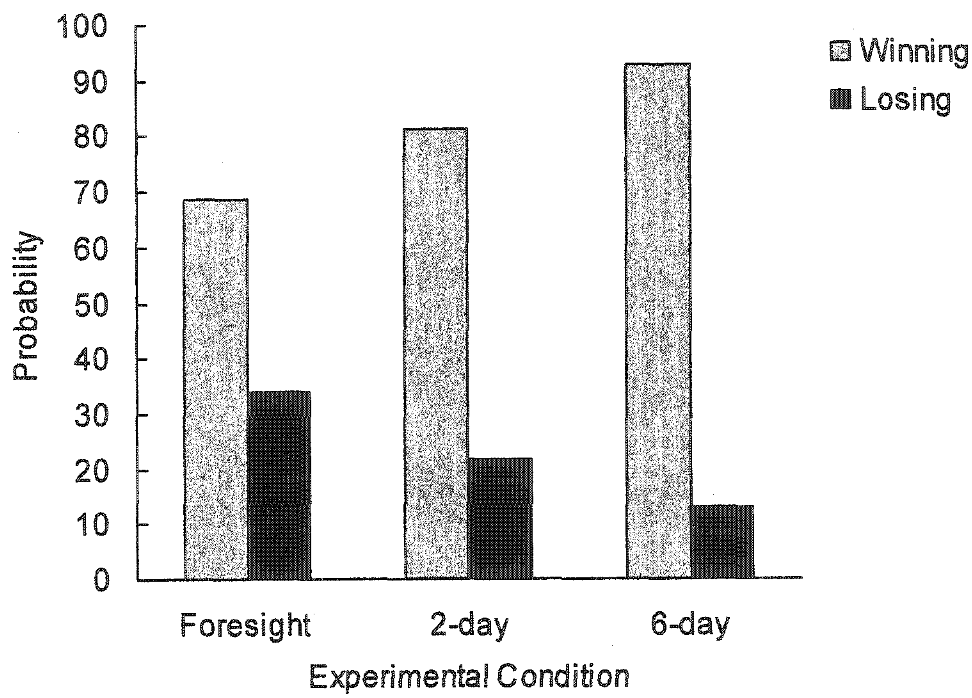

Table 4.

Comparison of Mean Subtest Scores. A comparison of mean subtest scores for 2-day and 6-day hindsight groups for Experiment 2.

Subtest	2-day	6-day
Overall	M = 0.69 SD = 0.01	M = 0.64 SD = 0.006
True favoring home team (THOME)	M = 0.71 SD = 0.21	M = 0.66 SD = 0.08
True favoring the opposition (TOPP)	M = 0.71 SD = 0.23	M = 0.51 SD = 0.31
False favoring home team (FHOME)	M = 0.42 SD = 0.19	M = 0.45 SD = 0.17
False favoring the opposition (FOPP)	M = 0.77 SD = 0.20	M = 0.81 SD = 0.27

Figure 10.

Differential forgetting. Memory for events that favored the Home Team faded slower than memories for events favoring the opposition.

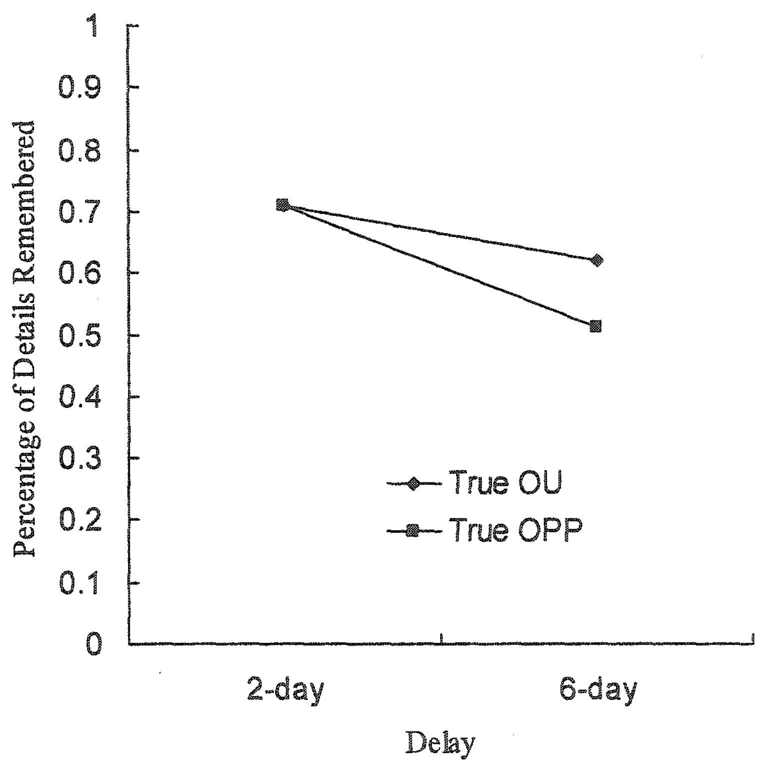

Table 5.

List of Categories

Main Category	Subcategory	Definition
Seeing	Seeing home team or opposition fans	No verbal interaction
	Watching other sporting events	
	Seeing sports or game paraphernalia	T-shirts, sports signs, flags, etc.
	Seeing home team athletes	
	Watching TV	Broadcasts pertaining to the game or team Local, national, ESPN
Listening	Radio comments	
	Passively listening to a discussion	Listening to other people, no participation
Discussion		Active participation in a discussion
Reading		Sport section of newspaper, magazines, websites, etc.
Journaling		Merely remembering to place an entry in the journal

Figure 11.

Revisiting proportions

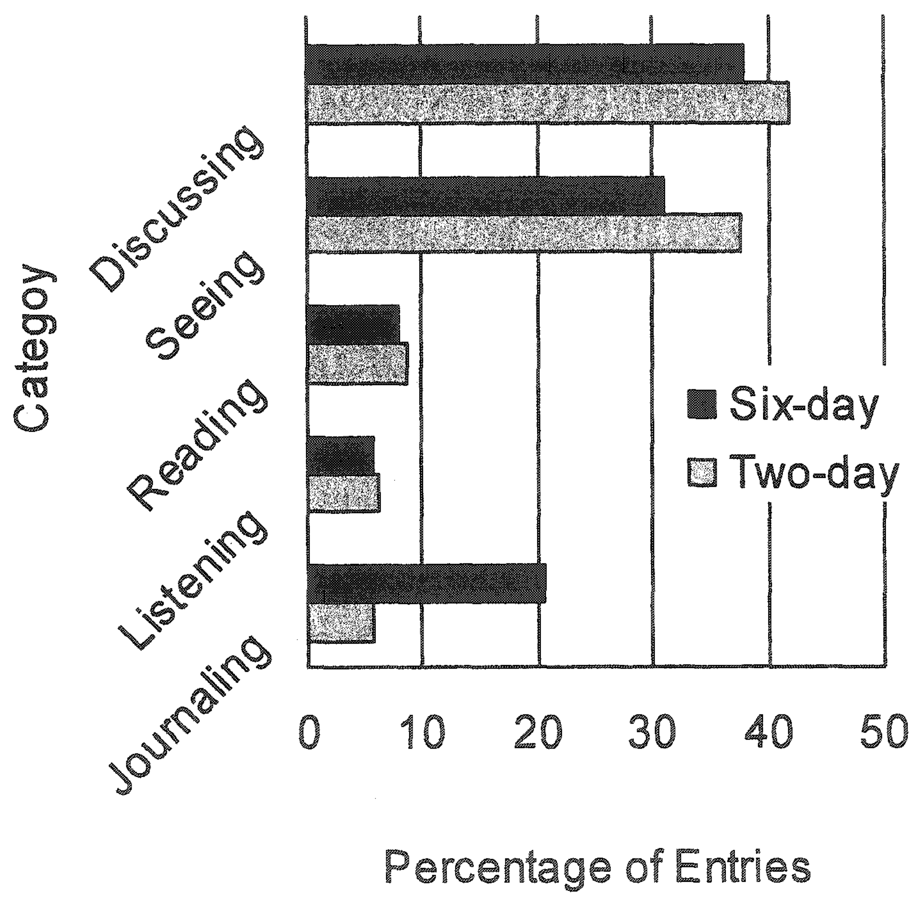

Figure 12.

Likelihood judgments from Experiment 2 (top panel) and MINERVA-DM estimates (bottom panel).