The Comprehension Processes and Memory Structures Involved in Instrumental Inference

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Instrumental inference was examined in several experiments using priming techniques. One technique allows examination of the relative state of activation of concepts in memory during reading, and a second technique allows the measurement of the relative distance between concepts in the memory representation of a text. The effect of the semantic relatedness between action and instrument on instrumental inference was examined. It was found that only instruments highly related to the action were activated by reading a sentence containing the action and that only instruments highly related to the action were connected to the action in the memory representation of the text.

The study of inference processes is gradually becoming a major concern in research on text processing. While work in artificial intelligence has centered on the interaction between the incoming information in a text being processed and world knowledge, research in cognitive psychology on the processes involved in inference has not progressed rapidly. One reason for this lack of progress is the difficulty of doing adequately controlled experiments. Another reason is the lack of adequate methodologies. In this paper, research on instrumental inferences (e.g., inferring *hammer* when someone was pounding a board) will be presented. We shall describe a simple three-component model for the inference process, and then we shall present several experiments that investigate these component processes and the resulting memory structures. We shall also argue that the methodologies presented here are superior to those previously used in the study of inference.

McKoon and Ratcliff (1980b), following previous work (Chafe, 1972; Clark, 1978; Haviland & Clark, 1974; Kintsch & Vipond, 1978), proposed a simple model for the processes involved in inference. First, the information to be inferred has to be accessed in memory. Second, the to-be-inferred concept has to be activated (or, equivalently, brought into short-term or working memory). Third, the information that caused the concept to be activated has to be connected to the concept. The connected structure, the result of the three processes, is the structure that is stored in long-term memory as a representation of the text. The experiments presented in this paper will use this three-process model as a theoretical analysis of the processes involved in instrumental inference.

The most popular method for the experimental study of instrumental inferences has involved the use of recall procedures. In a typical experiment the subject reads a list of short texts (usually sentences) and then, after the end of the list, is presented with a list of cues (single words) and is asked to recall the sentence that is suggested by each cue. It has been shown that a cue that represents information that could have been inferred from a sentence will function as an effective retrieval cue (c.f. Anderson & Ortony, 1975; Anderson, Prichert, Goetz, Schallert, Stevens, & Trollip, 1976; Bar-

clay, Bransford, Franks, McCarrell, & Nitsch, 1974; Paris & Lindauer, 1976; Till, 1977). For example, given the sentence *The container held the apples,* the cue *basket* will be more effective as a retrieval cue than *bottle* (Anderson & Ortony, 1975).

Although cued recall studies demonstrate that subjects *can* make the inferences represented by the cues, no conclusions can be drawn about *when* the subjects make the inferences. It could be that the inferences are made during reading or it could be that they are made at the time of the cued recall test. In other words, the inference process studied in cued recall tasks could be either an encoding or a retrieval phenomenon or both (see Tulving, 1976).

In general, the authors of cued recall studies argue that the inferences made in their tasks are an encoding phenomenon (c.f. Anderson, Goetz, Pichert, & Halff, 1977; Anderson & Ortony, 1975; Till, 1977). However, two recent studies suggest that they are in fact a retrieval phenomenon. A study by Singer (1978) indicates that subjects use the recall cues to "work backwards" to the sentences to be recalled. In one of his experiments, Singer compared the effectiveness of two recall cues that differed in forward and backward association to the action expressed by the to-be-recalled sentence. For example, the association from the cue *ladle* to the action *stirring soup* is strong, while the reverse association (*stirring soup* to *ladle*) is weak. On the other hand, the association from *spoon* to *stirring soup* is weak while the reverse association is strong. Results showed that *ladle* was a better recall cue than *spoon,* suggesting that subjects generated backward associations from *ladle* in order to recall *stirring soup.* This study supports the view that the inferences demonstrated in cued recall experiments are the result of retrieval phenomena. Further support for this view was obtained by Corbett and Dosher (1978). The to-be-remembered sentences in their experiment included sentences like *The worker pounded the nail,*

The worker pounded the nail with the hammer, and *The worker pounded the nail with the rock. Hammer* was equally effective as a retrieval cue for all three sentences. This result contradicts the view that an implied instrument is an effective retrieval cue because it was inferred during encoding, and supports the view that the inferences that have been studied with the cued recall technique are retrieval phenomena.

This discussion indicates that instrumental inferences may not be routinely made during reading. From a theoretical point of view, if the aim of reading is to form a coherent, connected representation of the text, then instrumental inferences are not usually necessary. In contrast, certain kinds of inference are necessary, for example, anaphoric reference. If the text mentions a concept such as *car* and a sentence or two later mentions an anaphor, *the vehicle,* then in order to make the proper connections, the inference that *the vehicle is the car* has to be made (see McKoon & Ratcliff, 1980b).

It is possible to identify two extreme views as to whether instrumental inferences are made: First, instrumental inferences are rarely made because these kind of inferences are rarely needed to produce a connected text representation. Second, instrumental inferences are always made because the schema being used to interpret the incoming text has slots for instruments and these slots are automatically filled either by an instrument provided in the text or by default values (e.g., Minsky, 1975). Probably the most reasonable position is that under some conditions instrumental inferences are made and under some conditions they are not made. The experiments reported in this paper are designed to investigate one of the factors that controls the probability that an instrumental inference will be made. This factor is the degree of semantic relatedness between the instrument and the action.

The experiments use two methods for the study of instrumental inference. In both,

the subject is required to respond as to whether a test word occurred in a previously presented text. A speedup in the response is assumed to show that the test word was activated (or perhaps brought into working memory) by information that immediately preceded the test word. Mc-Koon and Ratcliff (1980b) used these methods to investigate the processes involved in anaphoric reference. In one procedure, the state of activation of concepts was examined by presenting a single word for recognition immediately after a text had been read by the subject (see also Caplan, 1972, and Chang, 1980). It was found that if the last sentence of the text mentioned an anaphor (e.g., *vehicle*), then response time to the referent (e.g., *car*) was decreased relative to a control condition in which there was no mention in the last sentence of words related to the referent or anaphor. The decrease in response time was interpreted as reflecting the activation of the referent by the anaphor. A second procedure, developed by Ratcliff and McKoon (1978; McKoon & Ratcliff, 1980a), was used to investigate the memory structures resulting from anaphoric reference. Subjects read two texts and then responded to a test list of words presented singly for recognition. A decrease in response time to a test word was found if the immediately preceding word in the test list was closely connected in the memory representation of the text by anaphoric reference. For example, if a text stated *the vehicle crashed into the snowman* and the referent *car* was presented earlier in the text, then *car* was found to prime *snowman* in the test list. This priming has been shown to be the result of automatic, not strategic, processes (Ratcliff & McKoon, 1981).

These two procedures were used in the experiments presented in this paper to investigate instrumental inference. First, the activation component of the inference process was examined by testing a single word for recognition immediately after a sentence was read. Second, priming in word recognition was used to look for the connections between concepts that result from the inference process.

EXPERIMENT 1

The aim of this experiment was to investigate the process of activation of an instrument by an action. We wished to answer the question, does mention of an action activate (or bring into working memory) an instrument that is highly associated to the action? Subjects read paragraphs sentence by sentence, and, after reading the last sentence of a paragraph, were presented with a single test word for recognition. Table 1 shows one example of the paragraphs used in this experiment. Two versions of the paragraph are shown; *hammer* is a likely instrument for the action of the final sentence in the first version of the paragraph but not in the second. The test word for the paragraph was *hammer*, whichever of the two versions was read. We expected that, when the final sentence mentioned *pound*, response time to *hammer* would be speeded relative to the condition in which the final sentence mentioned *stuck*. This priming effect would be taken as evidence for the activation of the concept *hammer* by the action *pounded the boards with nails*.

Method

Subjects. The subjects were 16 Dartmouth undergraduates who participated in the experiment for extra credit in an introductory psychology course.

Materials. Forty-two paragraphs like the one shown in Table 1 were written. There were four sentences in each paragraph, plus the two versions of the fifth sentence. The critical word, the instrument for the action of one of the final sentences, always appeared in the first sentence of a paragraph (e.g., *hammer* in Table 1). This instrument had the highest production frequency for the action, according to norms collected by Corbett and Dosher (Note 1). The two versions of each final sentence were always

TABLE 1
An Example of the Paragraphs
Used in Experiment 1

Test word: *hammer*

Bobby got a saw, hammer, screwdriver, and square from his toolbox.

He had already selected an oak tree as the site for the birdhouse.

He had drawn a detailed blueprint and measured carefully.

He marked the boards and cut them out.

Final sentence, version 1:
Then Bobby pounded the boards together with nails.

Final sentence, version 2:
Then Bobby stuck the boards together with glue.

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identical in wording except for the verb and occasionally one other word. The test word for each paragraph was the critical word (e.g., *hammer*).

Sixty more paragraphs were written to serve as fillers. There were 10 four-sentence paragraphs with test words which were not in the paragraphs (negative test words), 15 four-sentence paragraphs with positive test words, 10 five-sentence paragraphs with negative test words, 10 six-sentence paragraphs with negative test words, and 15 six-sentence paragraphs with positive test words.

Procedure. Subjects were tested individually in one 50-minute session. Presentation of all materials was controlled by a microcomputer driven by Dartmouth's time-sharing computer system.

Each subject read 9 practice paragraphs, the 42 experimental paragraphs, and the 60 filler paragraphs. Presentation of each paragraph began with an instruction to the subject to press the space bar on a CRT keyboard to initiate the paragraph. Then the first sentence of the paragraph appeared on the screen. The subject was instructed to read it carefully and press the space bar when he was sure he understood it. When the space bar was pressed, the first sentence disappeared from the screen and the second sentence appeared. The subject continued in this way through the sentences

of the paragraph. When the subject pressed the space bar after reading the final sentence of the paragraph, a row of asterisks with the test word below it appeared on the screen. The subject was instructed to respond to the test word by pressing either a "yes" or a "no" key (the "/" and "z" keys, respectively, on the CRT keyboard), according to whether or not the test word had appeared in the paragraph. Subjects were instructed to respond as quickly and accurately as possible. The test word remained on the screen until a response was made; then it disappeared from the screen and the instruction to press the space bar to begin the next paragraph appeared. Because of the variable number of sentences in the filler paragraphs, the subject did not know which was the final sentence until after he had finished reading it and pressed the space bar. A different random order of presentation of paragraphs was used for each two subjects.

In an effort to persuade subjects to read the paragraphs carefully, a sentence verification test was given after every six paragraphs. One sentence was chosen from each paragraph; if it was to be a false test item, one word was changed to alter its meaning. Half of these test items were false, half were true.

Design. There were two experimental conditions; the final sentence of a paragraph represented either an action for which the critical instrument was appropriate or an action for which it was inappropriate. The first four sentences and the test word for a paragraph were always the same; only the final sentence varied. The two experimental conditions were crossed with two groups of subjects (eight per group) and two sets of paragraphs (21 per set) in a Latin-square design.

Results and Discussion

For responses to test words, any time longer than 2500 milliseconds was eliminated from the analyses. (As was true in all the experiments in this paper, this cutoff

eliminated no more than 3% of responses, approximately equally across experimental conditions.) All analyses were based on mean response times for each subject or item in each condition. Means of these means are shown in Table 2. The average, across the two experimental conditions, of the standard errors of the response times was 57 milliseconds; the average for reading times was 90 milliseconds.

In one of the experimental conditions, the final sentence of the paragraph mentioned an action (*pound*) appropriate for the instrument (*hammer*) mentioned in the first sentence. In the other condition, the action (*stick*) mentioned in the final sentence was not appropriate. If the final sentence with the appropriate action served to activate the instrument or bring it into working memory, then response time to the instrument (the test word, *hammer*) should be faster in this condition than the other condition. Comparison of response times in the two conditions showed this difference significant, $F(1,15) = 5.6$, $p < .04$, with subjects as a random variable and $F(1,40) = 6.1$, $p < .02$ with materials as a random variable. Thus it appears that the appropriate action did activate the instrument.

Reading times for the final sentences in the two experimental conditions are not directly comparable because the two versions differed in the verb. The final sentences that expressed an action inappropriate to the instrument mentioned in the paragraph took slightly longer to read ($F(1,15) = 2.3$, $p = .15$, subjects analysis, and $F(1,40) = 3.4$,

$p = .07$, materials analysis). This effect may be attributed either to differences in the verbs or to differences in the interaction between the verbs and the other sentences of the paragraphs.

Experiment 2

This experiment was designed to indicate the effect of the semantic relatedness between the action and the instrument on activation of the instrument. The first experiment showed that an action produced activation of an appropriate instrument when that instrument was highly associated to the action according to production frequency norms (Corbett & Dosher, Note 1). In the second experiment, we asked whether an action would produce activation of an appropriate instrument even if the instrument was not highly associated. For example, *pound* produced activation of *hammer*, but would it produce activation of *mallet* (see Table 3)?

Method

In general, Experiment 2 was like Experiment 1. The major difference was in the instrument mentioned in the first sentence of each paragraph (which was also the test word). Corbett and Dosher (Note 1) have shown that, given the appropriate action, the instruments used in Experiment 2 are produced with low frequency, in contrast with the instruments used in Experiment 1 which are produced with high frequency. For example, the paragraph in Table 3 differs from the paragraph in Table 1 only in

TABLE 2
READING TIMES FOR FINAL SENTENCES AND RESPONSE TIMES AND ERROR PERCENTAGES (IN PARENTHESES) FOR TEST WORDS IN EXPERIMENTS 1 AND 2

Final sentence	Experiment 1 Test word: *hammer*		Experiment 2 Test word: *mallet*	
	Final sentence reading time (msec)	Test word response time (msec)	Final sentence reading time (msec)	Test word response time (msec)
Pound	1542	981 (24)	1531	823 (18)
Stick	1629	1039 (30)	1525	818 (20)

TABLE 3
An Example of the Paragraphs Used in Experiment 2

Test word: *mallet*

Bobby got a saw, mallet, screwdriver, and square from his toolbox.

He had already selected an oak tree as the site for the birdhouse.

He had drawn a detailed blueprint and measured carefully.

He marked the boards and cut them out.

Final sentence, version 1:
   Then Bobby pounded the boards together with nails.

Final sentence, version 2:
   Then Bobby stuck the boards together with glue.

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the mention of *mallet* instead of *hammer* in the first sentence. In Corbett and Dosher's norms, *mallet* was produced in response to the action *pound* with low frequency while *hammer* was produced with high frequency. In all respects other than the instrument, the paragraphs were the same as those used in Experiment 1, except that only 40 experimental paragraphs were used.

Results and Discussion

The results are shown in Table 2. Response times (for the test words) longer than 2500 milliseconds were eliminated from the analyses and all analyses were based on mean response times for each subject or each item in each condition. The average standard error for response times was 82 milliseconds and, for reading times, 216 milliseconds.

If the final sentence that mentioned *pound* served to activate the instrument *mallet,* then response times for the test word *mallet* should be faster in this condition than in the condition where the final sentence mentioned *stick.* This result was not found; responses to the test word did not differ in speed in the two conditions, F's < 1. Thus, it appears that an action does not activate an appropriate instrument when that instrument is not highly associated to the action. Reading times of the final sentences also did not differ reliably, F's < 1.

EXPERIMENTS 3 AND 4

Experiments 1 and 2 showed one of the component processes of inference, that is, activation of the to-be-inferred concept. The purpose of Experiments 3 and 4 was to investigate another component process, the connection of the to-be-inferred concept to the information that activated it. Experiment 3 was concerned with actions and instruments that are highly related and Experiment 4 used actions and instruments with lower relatedness. For example, in Experiment 1, in the paragraph in Table 1, the proposition (POUND, BOBBY, BOARDS, NAILS) activated the concept *hammer.* The question addressed in Experiment 3 was whether *hammer* would be connected to this proposition in the long-term memory representation of the paragraph. Similarly, Experiment 4 examined whether an instrument not so highly associated to the action (e.g., *mallet*) would be connected and stored in long-term memory.

Experiments 3 and 4 used priming in word recognition; a study–test procedure was used. On each trial, subjects studied two paragraphs and then were tested for recognition of single words. The extent to which two concepts were connected in the memory representation of a paragraph was measured by the amount of priming between them when they were presented sequentially in the test list. For example, *hammer* should prime *boards* more when the final sentence mentions *pound* than when it mentions *stick.* However, *boards* should be primed to some extent by *hammer* even when the last sentence mentions *stick,* because *hammer* and *stick* are in the same paragraph, although far apart. Included in the experiments was a condition where *boards* was unprimed, that is, the immediately preceding word in the test list was a word from the other paragraph in the study list.

Method

Subjects. In each experiment, there were 24 subjects, Dartmouth undergraduates

participating for extra credit in an introductory psychology course.

Materials. The paragraphs used in Experiment 3 were the 40 paragraphs of Experiment 1 that were modified for use in Experiment 2. The paragraphs used in Experiment 4 were those used in Experiment 2. In Experiment 3, the first sentence of each paragraph mentioned an instrument highly associated to the action of one of the versions of the final sentence (e.g., *hammer* is highly associated to *pound*). In Experiment 4, the first sentence of each paragraph mentioned an instrument less highly associated to the same action (e.g., *mallet* is less highly associated to *pound* than *hammer*). In both experiments there were two versions of each paragraph, which differed only in the verb (and sometimes one other word) of the final sentence.

There were four positive test words for each paragraph. One was the target word, a noun in the final sentence of the paragraph. For the paragraphs in Tables 1 and 3 (that is, for both Experiments 3 and 4), the target word was *boards*. The second positive test word was the instrument mentioned in the first sentence, *hammer* in Experiment 3 and *mallet* in Experiment 4. The other two positive test words were nouns from the middle sentences of the paragraph. For each paragraph, there were also four words that did not appear in the paragraph; these were to be used as negative test words.

Procedure. A study–test recognition memory procedure was used. Each subject received three trials for practice and 20 experimental trials.

The study list for each trial was made up of two paragraphs chosen randomly without replacement from the 40 paragraphs. The test list for each trial consisted of 16 words, 8 positive and 8 negative. The test list was constructed in the following manner: First, the target words (one for each studied paragraph) were placed in randomly chosen positions in the list, except not in positions 1 or 2. Then, if the word was to be primed by the instrument of its paragraph, this instrument was placed in the immedi-

ately preceding test position. If the word was to be unprimed, a word from the other studied paragraph was placed in the immediately preceding test position. Finally, the remaining positive test words and the negative test words were placed randomly in the remaining positions of the test list. Restrictions were that a word from one of the studied paragraphs could not precede the target word of that paragraph by fewer than three positions and that no word could appear more than once in the test list.

Subjects began each trial by pressing the space bar of the CRT keyboard. The first sentence of the paragraph was then presented for study, for 3.5 seconds if it was a one-line sentence, 5.5 seconds if it was a two-line sentence. Each succeeding sentence was presented in the same way. After the final sentence, a row of asterisks appeared for 3.5 seconds, and then the second paragraph was presented in the same manner as the first. After the second paragraph, there were two rows of asterisks (4.5 seconds) and then the test list began immediately. The test words were presented one at a time. Each remained on the screen until the subject made a response, pressing a "yes" key if the word had appeared in either of the studied paragraphs, a "no" key otherwise. Subjects were instructed to respond as quickly and accurately as possible. The next test word appeared 150 milliseconds after the response to the preceding test word.

Design. There were three experimental conditions in each experiment. The target word (*boards*) was primed by the instrument (*hammer* in Experiment 3, *mallet* in Experiment 4) when the final sentence mentioned the appropriate action (*pound*) or when the final sentence mentioned the inappropriate action (*stick*), or the target was unprimed (preceded by a word from the other studied paragraph). If the target were unprimed, then the final sentence was chosen randomly from the two versions. The three experimental conditions were combined with three groups of subjects (eight per group) and three sets of para-

graphs (13 per set) in a Latin-square design. (The 40th paragraph provided an even number of paragraphs for the study lists.) A different random order of presentation of materials was used for every two subjects.

Results and Discussion

All response times longer than 1500 milliseconds were eliminated from the analyses. Only correct responses preceded by correct responses were included in the analyses in order to be as sure as possible that both the priming and target words were in memory. All analyses were based on mean response times for each subject or each item in each condition. The results are shown in Table 4. The average, across the three experimental conditions, of the standard errors for response times was 13 milliseconds in Experiment 3 and 20 milliseconds in Experiment 4.

In both experiments, response times to the target word differed across the three priming conditions. In Experiment 3, this result was significant, $F(2,46) = 31.9, p < .001$, with subjects as the random variable and $F(2,72) = 26.7, p < .001$, with materials as the random variable. In Experiment 4, the result was significant, $F(2,46) = 19.9, p < .001$ (subjects analysis) and $F(2,72) = 17.3, p < .001$ (materials analysis).

In both experiments, responses in the unprimed condition were slower than re-

sponses in the primed conditions. This result simply reflects the advantage given by priming with a word from the same paragraph as the target relative to the condition in which the target is preceded in the test list by a word from the other studied paragraph.

The question of interest in these experiments concerned the process of connecting the instrument to the action of the final sentence, when the instrument was appropriate for the action. In Experiment 3, where the instrument was highly associated to the action, it appears that this connection was made. When the final sentence mentioned an action that was appropriate for the instrument (e.g., pound for hammer), then the priming effect of the instrument on the target word (hammer−boards) was larger than when the final sentence mentioned an inappropriate action (stick). This difference was significant, $F(1,46) = 6.0, p < .02$ (subjects analysis) and $F(1,72) = 5.4, p < .03$ (materials analysis). In Experiment 4, where the instrument was not highly associated to the action, it appears that the connection was not made. The priming effect of the instrument on the target word (mallet−boards) did not differ significantly between the two final sentence conditions, $F < 1$ in both subjects and materials analyses. The error data suggest that there may be a speed−accuracy tradeoff problem

TABLE 4
Response Times (msec) and Error Percentages (in Parentheses) for Target Words in Experiment 3 and 4

Priming condition	Experiment 3 Instrument: hammer	Experiment 4 Instrument: mallet
Instrument: boards Final sentence: pound	604 (02)	655 (01)
Instrument: boards Final sentence: stick	630 (02)	648 (04)
X[a]: boards Final sentence: stick or pound	688 (09)	722 (11)

[a] X is some word from the other paragraph in the study list.

in this experiment, but the difference in error rate for the two priming conditions is not significant by either subjects or materials analyses.

EXPERIMENT 5

The results of Experiment 3 appear to indicate that in the memory representation of the text connections are made between the sentence containing the action and the instrument when the instrument and action are highly related. There is, however, an alternative interpretation of these results. It could be that *hammer* primes *boards* when the final sentence mentions *pound* because there is a preexperimental semantic association between *hammer* and *pound*. *Hammer* primes *pound* because of this association and *pound* in turn primes *boards*. Therefore, the priming effect of *hammer* on boards is not due to inference processes that connect the instrument *hammer* to the action *pound the boards*. Experiment 5 was designed to rule out this alternative interpretation.

An example of the paragraphs used in Experiment 5 is shown in Table 5. In the first sentence, *hammer* is mentioned but it is not available for use because it is broken. In the first version of the paragraph, the final sentence states that the boards were pounded together. In the second version, the boards were stuck together. If, in Experiment 3, the priming effect of *hammer* on *boards* was due to preexperimental semantic association between *hammer* and *pound*, then there should be a similar priming effect in this experiment. On the other hand, if the effect in Experiment 3 was due to inference processes, then it will not be observed in this experiment. The hammer could not be inferred to be the instrument because it was broken.

Method

Subjects. There were 34 subjects from the same population as the other experiments.

Materials. The materials were the same as those used in Experiment 3, modified

TABLE 5
An Example of the Paragraphs
Used in Experiment 5

Bobby opened his toolbox and pulled out a mallet, a hammer which had been broken earlier that week, and a screwdriver.

He also collected the lumber and paint he had bought.

He had already selected an oak tree as the site for the birdhouse.

He had drawn a detailed blueprint and measured carefully.

He marked the boards and cut them out.

Final sentence, version 1:
Then Bobby pounded the boards together with nails.

Final sentence, version 2:
Then Bobby stuck the boards together with glue.

like the example shown in Table 5.

Procedure. The procedure was the same as in Experiment 3.

Design. There were two experiment conditions. The target word (*boards*) was primed by instrument highly associated to the action (*hammer*) either when the final sentence mentioned the appropriate action (*pound*) or when the final sentence mentioned an inappropriate action (*stuck*). The two experimental conditions were combined with two groups of subjects (17 per group) and two sets of paragraphs (20 per set) in a Latin-square design. A different random order of presentation of materials was used for every two subjects.

Results and Discussion

All response times longer than 1500 milliseconds were eliminated from the analyses. Only correct responses preceded by correct responses were included in the analyses in order to be as sure as possible that both the priming and target words were in memory. All analyses were based on mean response times for each subject or each item in each condition. Average standard error was 18 milliseconds.

Response times did not differ significantly between the two experimental conditions, F's < 1. When the final sentence mentioned the appropriate action, mean re-

sponse time was 657 milliseconds (7.5% errors). When the final sentence mentioned the inappropriate action, mean response time was 643 milliseconds (9% errors).

The results of Experiment 5 show no priming between *hammer* and *board*. Thus, the results of Experiment 3 can be attributed to inference processes and not to preexperimental semantic association.

GENERAL DISCUSSION

In this paper we have investigated some of the processes and memory structures involved in instrumental inference. The results are interpreted in terms of a simple three-component model of the inference process: First, a concept to be inferred has to be accessed in memory. Second, the concept, along with its associated propositions, has to be activated. Third, the information responsible for the activation has to be connected to the concept and its associated propositions and the result stored in long-term memory.

To investigate the components of the inference process, two relatively new methodologies were employed. Both methodologies involve testing a single word for recognition. In the activation procedure, the text is presented to the subject sentence by sentence. Immediately after the last sentence, a test word, which has appeared earlier in the text and which represents a to-be-inferred concept, is presented for recognition. When the concept is inferred during comprehension of the last sentence, response time to the test word is speeded (McKoon & Ratcliff, 1980b). This procedure was used to investigate the state of activation of instruments in the process of instrumental inference in Experiments 1 and 2. In the second method, priming in word recognition, subjects are presented with two paragraphs and are then presented with a test list of single words for recognition. If successive test words are connected in the memory representation of the text, then response time to the second word is decreased relative to the condition in which the two words are not connected (McKoon

& Ratcliff, 1980a, 1980b; Ratcliff & Mc-Koon, 1978, 1981). This second priming technique was used to investigate whether an instrument was connected to the action requiring the instrument.

Before summarizing the results of the experiments and discussing implications for inference processing, we need to discuss what it means to obtain a significant priming effect. First, a significant priming effect does not necessarily mean that all subjects have activated the instrument (or made the connection between the action and the instrument) for all the materials in the experiment. Rather we can only conclude that enough of the subjects on enough of the materials produced the priming to result in a significant effect. Therefore the lack of a significant priming effect only shows that relatively few of the subjects over relatively few of the materials produced the effect. The conclusions presented below are all predicated on this interpretation.

The experiments presented in this paper examine the effect of semantic association on the activation of concepts and the structure of the memory representation in instrumental inference. The first experiment shows that *hammer* is activated by presentation of *Bobby pounded the boards* (note that *hammer* was mentioned earlier in the text). The second experiment used instruments that are not so highly related to the action (e.g., *mallet* instead of *hammer* to the action *pound*). Results from this experiment show that these instruments are not activated by the action. Thus, relatedness has an effect on the activation process. The third and fourth experiments examined the memory structure that results from instrumental inference. The memory structure reflects the process that connects propositions containing the action to propositions containing the instrument. The third experiment shows that a highly related instrument is in fact connected to the action, while the fourth experiment shows that a less related instrument is not connected to the action.

The question arises as to when the in-

strumental inference occurs, at the time the sentence describing the action is read or at the time the instrument is presented as a test word. Either would be a reasonable possibility in Experiment 1. Reading about the action could cause the instrument to be activated and connected to the action (thus speeding response time at the subsequent presentation of the instrument as a test word). Or reading and responding to the instrument as a test word could be speeded because the instrument is easily connected to the still active action. However, in Experiment 3, the instrument test word is presented in the midst of a list of other test words, so it seems unlikely that it would instigate the activation of the action. Thus, it is suggested that instrumental inference occurs at the time the sentence describing the action is read, at least in the paragraphs used in these experiments.

In conclusion, we can ask what is the status of our knowledge about instrumental inference? Do readers make instrumental inferences? The results of the experiments described in this paper suggest that the picture is more complicated than a simple do or don't dichotomy. Clearly semantic relationships between the action and instrument affect the process of instrumental inference. Probably, there are many other interacting factors that will have to be taken into account to predict whether a particular instrumental inference will be made. Furthermore, the interacting factors may have differential effects on the different subprocesses of the instrumental inference process. On the other hand, if the interactions of these factors can be understood, then a simple model of the processes driven by these factors, a model such as the three-factor model described earlier, may be able to provide a good description of processing and the resulting memory structure.

Perhaps the reason that instrumental inference is complicated is that it is not usually necessary for comprehension. For example, it may be necessary to know only that the boards were pounded together and not necessary to know with what they were

pounded. If such inferences are necessary or subjects set the goal of making instrumental inferences, then the processes by which the inferences are made may be able to be described by relatively simple principles (e.g., McKoon & Ratcliff, 1980b).

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