Title
Spatial Inferences and Discourse Comprehension

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 7(0)

Authors
Wender, Karl F.
Wagener, Monkia

Publication Date
1985

Peer reviewed

Spatial inferences and discourse comprehension

Karl F. Wender and Monika Wagener
Technische Universitat Braunschweig

ABSTRACT

Theories of discourse comprehension and memory for text usually assume a propositional format in which information is stored. In agreement with the work on mental imagery we argue that information from texts may also be remembered in a spatial representation. Inference processes with spatial relations depend on the format of the mental representation. In two experiments we employed a priming technique to show spatial properties of mental representation. The first one using narratives failed to yield positive results. The second experiment using spatial descriptions supported the hypothesis. Decision times in a priming task were dependent on spatial distances. The relationship between inference processes and the form of the mental representation is discussed.

This research investigates the interaction between the mental representation of a text and inference processes that operate on this representation. The main idea is that inference processes depend to a certain extent on the form of the mental representation.

Aspects of mental representation of discourse have been investigated by many researchers in recent years. One question is whether information is stored in a propositional network or in a more analogous format. For information from discourse it is not obvious how objects and events described in a text are mentally represented. It is conceivable that the type of representation depends on the reading task or the goal of the reader.

Most models of text comprehension propose a propositional format. On the other hand, if someone has to make spatial judgements of some sort it might be more efficient to construct a spatial mental representation. Some authors, most notably Johnson-Laird (1983), argue that mental representations of texts often take on an analogous, spatial form.

The notion that subjects may use different strategies depending on the nature of the task is supported by results from Ohlsson (1984). He was able to show that in a spatial reasoning task subjects switched between two procedures called series formation and elimination. In present terms series formation would imply the construction of a spatial mental representation whereas elimination would correspond to inference processes using a propositional representation.

Graesser (1977) showed the influence of a spatial representation on sentence comprehension. It is our goal to show that such spatial representations are also constructed during reading of discourse. This is an intuitively plausible hypothesis. However, it is not that easy to find empirical support.

Experiments by Mani and Johnson-Laird (1982) and by Ehrlich and Johnson-Laird (1982) give experimental support to these notions. However, their experimental materials were not stories but rather simple descriptions of the spatial relation between objects. An experiment by Black, Turner, and Bower (1979) demonstrates the role of point of view in narrative comprehension. This result also suggests a spatial representation.

The present study uses a different experimental technique. A procedure which has been successfully used by several authors is the priming technique (Meyer and Schvaneveldt,1971). A priming effect has already been observed in studying representations of sentences and discourse. Ratcliff and McKoon (1978) showed that in a recognition task words from the same sentence primed each other more than words from different sentences. Guindon and Kintsch (1984) used this method to demonstrate that readers had formed macropropositions during reading. In a recent study by McNamara, Ratcliff, and McKoon (1984), the priming technique was applied successfully to spatial representations of maps with routes and cities.

Experiment 1

In our first experiment, we try to show that the priming method works also on spatial representations of narrative texts.

Method

We employed a procedure that has been used by McKoon & Ratcliff (1981) to prove the influence of instrumental inferences.

In our experiment, subjects read short stories that were presented sentence by sentence on a CRT screen. Subjects were instructed to read each sentence and to press a button when they felt that they had understood the sentence. Following the last sentence a single word appeared on the screen. Subjects had to decide as fast as possible whether this word had been mentioned in the preceding text or not. Decision time was measured.

Subjects

Subjects were 24 students of the Technische Universität Braunschweig. They were paid DM 10,-- for their participation.

Material

Each subject read 24 short stories plus 6 additional ones for warming-up purposes. Half of the 24 stories were experimental stories. The remaining 12 were distractor stories. Each experimental story consisted of five or six sentences describing everyday events. In each story three relevant objects were mentioned. The stories were constructed in such a way that two of the objects were spatially close to each other. The third one was further away. An example is the following story about "Hans smoking at school: After school, Hans is smoking in the classroom. This, of course, is not allowed and he must be very careful. Suddenly a teacher comes around the corner. Hans just manages to throw the cigarettes under the table. Previously he had hidden the cigarettes behind the curtain. With an innocent smile he looks to the table."
The three relevant objects are the table, the curtain, and the cigarettes. At the end of the story the cigarettes and the table are close to each other whereas curtain and cigarettes are farther apart. On the other hand, the text was written in such a way that the propositional or network distance between table and cigarettes is equal to the distance between curtain and cigarettes.

In the last sentence in the story the last word mentioned is table which served as the close prime. To investigate the difference in priming effect between close and distant primes we wrote a second version of each text in which the last sentence was replaced by. "With an innocent smile he looks to the curtain." This sentence should activate the concept curtain which served as the distant prime. Thus, decision time should increase.

To control for semantic associations between table and cigarettes as well as between curtain and cigarettes, there were two corresponding versions in which the roles of table and curtain were interchanged. Thus, curtain was the close prime and table was the distant prime.

Procedure

Texts were presented sentence by sentence on a CRT screen. Subjects were instructed to step on a pedal when they had understood a sentence. Then this sentence was replaced by the next one. Subjects were instructed to imagine each described scene as vividly as possible. After the final sentence the target word appeared and subjects had to respond by pressing a yes or a no button. They had to decide whether the target word had been presented in the text.

We expected a priming effect of the concepts contained in the sentence immediately preceding the target. In particular we looked at the priming effects of table vs. curtain with respect to cigarettes. If subjects form a mental representation like a semantic network then the decision times for the target word cigarettes should not differ under the two priming conditions. If, on the other hand, subjects construct a spatial representation, then the closer prime should have a facilitating effect on the target. Thus the decision time following the prime table should be shorter compared to the time following the prime curtain.

Results and Discussion

The results of the experiment were not as expected. Mean decision times were 1103 ms for the close prime and 1088 ms for the distant prime condition. This difference is not significant and does certainly not support the hypothesis of a spatial representation.

There may be several reasons why the experiment failed. Perhaps our texts did not give enough clues for a spatial representation. Or it may be that subjects had to read too many stories. Furthermore, it is possible that the experimental task did not neccessarily require a spatial representation. Some subjects reported that they instead compiled a list of concepts mentioned in the text and then compared the target with this list.

Experiment 2

Method

To avoid the problem of too many stories we to used a priming technique that does not need stories as foils. Furthermore, we changed the material completely, bebause stories like those in Experiment 1 always contain many things more than just spatial relations.

An additional crucial change concerned the learning task for the subjects. They now learned short texts that described spatial configurations of five common things. To make sure that all subjects formed a similar spatial representation they had to arrange real objects according to each description. The learning phase of the experiment was followed by a priming phase and a verification test.

In the priming phase subjects had to decide whether pairs of objects belonged to the same configuration or not. Following the spatial representation hypothesis the decision time should depend on the distance between the two objects of the judged pair.

In a following the verification test subjects had to decide whether sentences of the form "object A is in relation R to object B" were true with respect to a specified configuration. Again decision time should depend on the distance between objects.

Subjects

Another group of 24 students participated in this experiment.

Materials

Eight short texts were written describing the spatial relationship between five objects. For example: "Vegetables: The paprika is in front of the cucumber. Left to the cucumber is the potato. In front of the potato is the onion. The tomato is in front of the onion."

Priming phase. From each configuration two pairs of words are of special interest. These are called the close pair and the distant pair according to the distances between the two respective objects. The spatial relationship between the two words of each of these pairs was not explicitly stated in the text but could be inferred by the reader. The predictions for these pairs were as follows. If subjects construct a spatial representation then the priming effect should depend on the spatial distance between prime and target within each pair. Thus, decision time should be shorter for the close pair than for the distant pair. If subjects do not use a spatial representation then decision times should be approximately equal.

There were two versions of each configuration in which the close pair and the distant pair were interchanged to control for the strength of semantic associations between the words of a pair. For example, in the second version of the text "vegetables" onion - paprika was the distant pair and cucumber - tomato was the close pair.

Verification test. Subjects read sentences that either agreed with the description or that contained a contradiction. For example "The onion is to the left of the paprika." would be a correct statement although it was not given in the original description. We call such a probe sentence an inference. Furthermore, we distinguish between close inferences, like the one given above, and distant inferences. A distant inference is for example: The potato is behind the tomato. The distance between these objects is twice as long as the distance between the objects of the close inference Following the spatial hypothesis distant inferences should take longer to verify than close inferences.

Procedure

In the first part of the experiment subjects had to learn the configuration extensively. In the second part we measured first the reaction times for the item recognition and then the verification times for complete sentences. The instruction given in the beginning did not explain the priming procedure and the verification test. The instruction only mentioned that some retention test would follow.

Learning phase. Each subject read eight short descriptions plus three additional ones for warming-up. Two different groups of subjects (Group A and Group B) were assigned to the two balanced versions of each story. Both groups got the same objects but with different configurations. Each description consisted of four sentences printed on a card. Subjects were instructed to read the text on the card as long as they wanted and to memorize them. Then they got a box containing one exemplar for each of the five objects. With these exemplars subjects had to build up the described configuration on a table in front of them.

Priming phase. The priming procedure took place at a CRT screen connected to a PDP-11. First, the title of one of the descriptions was presented on the screen. Subjects were instructed to visualize as vividly as possible the corresponding configuration. When they were ready they stepped on a pedal. The title disappeared and a fixation point was presented for 1 s. Then the first word was shown for 250 ms. There was an interstimulus intervall of 250 ms before the second word followed. This word remained on the screen until the subject responded. Subjects were instructed to rest their index fingers on two touch keys. They had to respond with yes or no by lifting one of their index fingers because reaction time was measured through the interrupt.

Verification Test. A similar procedure was used as in the priming test. Each trial began with the presentation of a title. Then eight test sentences followed. Half of these were correct and half were incorrect probes. The foils used the same objects, but placed them into wrong spatial relationships.

Results

Priming data. Decision times were analysed by a 2x2 analysis of variance. The factors were type of probe (close vs. distant) and groups of subjects. The mean decision times for the close and distant probes were 752 ms and 850 ms respectively. The mean decision time for the stated probes was 730 ms which is very close to the close pair. However, the stated probes were not included in the analyse because they contained different words. The difference between the distant probe and the close probe was significant ($minF'(1, 19) = 7.38$, $p < .02$). The difference in reaction times between the two groups of subjects did not reach significance. There was no significant interaction between the type of probes and the groups of subjects.

The percentages of correct responses under all conditions were very high. The mean percentages for the close pairs and the distant pairs were both equal to 98.5 %. The percentage was 98.9 % for the stated probes. The mean percentage of correct answers for all pairs including the foils was 98.8. There were no significant differences.

Verification test. The verification times were not as expected. Averaged over both groups of subjects the verification of the close inference took the longest time vs. groups of subjects. The stated probes were verified faster than both inference types.

The percentage of correct responses was generally lower than in the priming data. But again there were no significant differences between the types of probes or the groups of subjects. The percentages were: 91.7 for the close inference, 91.2 for the distant inference, 94.0 for the stated probes, and 94.1 averaged for all probes including the foils.

Discussion

The main result of our second experiment is the priming effect. The close pair was recognized significantly faster than the distant pair. This result is in accordance with our hypothesis that subjects have built a spatial representation. However, we have to interpret this result with some caution.

To begin with, we have not proven that a spatial representation is the only one that can explain our data. What our data imply is that subjects did not use a representation corresponding to a propositional encoding of the original description. In such a propositional network the distances within the close and the distant pair would be equal. Therefore, under the usual assumptions about the spread of activation, the decision times should be approximately equal. On the other hand, we cannot reject the possibility that subjects have formed a propositional net. It might be that they elaborated this network in a way that would also lead to a prediction of our data.

The following consideration is an indirect argument against a propositional representation. From the work of Guindon and Kintsch (1984) one would expect that subjects, when using a propositional representation, would also form macropropositions. A macroproposition which would help to remember a particular configuration could be a proposition stating that the five objects belonged to the given configuration. If a subject had formed this macroproposition it would be unlikely that she or he did not use it in the recognition task. However, from such a macroproposition one would predict equal recognition times for the close and distant pairs. This expectation is contradicted by our data.

If subjects have in fact built a spatial representation then we assume that this representation has properties that are in some sense functionally equivalent to those of an actual scene. This means that the space is continuous and distances are determined by an Euclidian metric. There are, however, other possibilities.

The first one is that the space may be discontinuous. In that case points in the space might resemble something like a lattice with unit distances in between. The distance between two points may then be determined by the number of intervening objects. In such a representation the relation between the objects of the close pair would be inherently given as unity. This would not be true with respect to the distant pair. In the hypothetical lattice the distance between the two objects would then be three. Our data do not allow us to distinguish between the continuous and discontinuous case.

Another possibility would correspond to the findings of McNamara et al. (1984) about the representation of cities on a map. Distances between cities may be either determined by the Euclidian metric or by the length of a route between them. It is conceivable that in our experiment subjects also have placed objects in their mental representation on something like a route. This route did not exist in the actual scene but could be constructed from the sequence of objects and their relationships mentioned in the text. In fact, some of our subjects reported that in the beginning they had built such a sequence. However, it appears that this must have been an intermediate state. Because the length on such a route and the number of intervening objects are equal for the close pairs and the distant pairs, the recognition times should be equal. Hence, our data allow us to reject this possibility for the representation of the configurations.

Coming to the inference processes it seems that the relationships between the objects of the close and distant pair that were not mentioned in the text have been integrated into the mental representation by the reader. Hence, there should be no difference between the stated relations and the implicit relation of the close pairs. This was in fact the case although comparison is not easily made because the probes involved different words.

Verification test. With respect to the verification task, our data are inconclusive. The only significant effect was an interaction that is difficult to interpret. Furthermore, the data show very large standard deviations (1500 ms and above). The explanation we like to offer is that the verification task was very difficult.

The reason might be an overload of working memory. It is possible that subjects needed almost the total capacity of their working memory for the image of the given configuration. In that case it might be impossible to execute all necessary processes: to comprehend the probe sentence, to hold the image, and to compare the meaning of the sentence with the imagined configuration. A capacity problem would arise, for example, when the reader has constructed a spatial image for the configuration and when he or she tries to construct a second one from the sentence to be verified. It is difficult to operate with two images at once. Hence, parts of the first configuration gets lost and the reader has to start over again. This enlarges the verification times and especially the standard deviations and masks other effects.

General Discussion

As said at the outset, it is our goal to show that readers construct spatial representations during discourse comprehension. Furthermore, we want to show that the inference processes on spatial representation are different from those on a propositional format. We have not yet reached this goal completely. For reasons discussed above the first experiment failed to produce the priming effect. In the second experiment our subjects got an additional task. Besides reading the texts they had to build the configurations with real objects. Obviously, this task has visual properties. Hence, we cannot claim that subjects have constructed their spatial mental representations exclusively during reading. However, it appears that subjects relied on the spatial representation when responding to the priming task. The time between prime onset and target onset used in our second experiment is short enough to ensure that subjects could barely start a process that was under their attentional control. We assume that our results are effected by an automatic process as discussed by Ratcliff and McKoon (1981).

The results are one step into the desired direction. What we have shown is that the priming technique is capable to reveal spatial information when people remember spatial descriptions. This was in doubt after our first experiment. The next step has to be a change in the experimental procedure such that subjects only read texts without any additional visual task intervening between reading and probing. The question then is whether the priming effect, dependent on distances, will be obtained again.

Let us consider now the relationship between the priming technique and inference processes. The task for the subject may be paraphrased as 'Did the configuration include the following two objects?'. In a propositional representation an inference process might consist of at least the following subprocesses: First, a search process must find nodes representing the two objects. Then the process has to find out whether the objects are linked to a proposition representing the configuration. Finally, the process has to decide whether the relations labeling the links can be interpreted in such a way that the question can be answered affirmatively. As suggested by the results of Ratcliff and McKoon (1978) this inference process takes less time when two concepts are linked together in the same proposition during reading. But this process should not depend on spatial distances unless the representation has some sort of spatial properties.

In a spatial representation the question can be answered simply by searching for the two objects. If they are found in the mental spatial representation then, by this virtue, they belong to the configuration. That is, in a spatial representation the include relation is inherently contained. The medium of representation is the spatial relation. The inference process then reduces to a search process. If this search process has equivalent temporal properties as the visual search the amount of time needed should depend on spatial distances in the mental representation. This was shown by our second experiment.

References

Black, J. B., Turner, T. J., & Bower, G. H. (1979). Point of view in narrative comprehension, memory, and porduction. Journal of Verbal Learning and Verbal Comprehension, 18, 187-198.

Ehrlich, K. & Johnson-Laird, P. N. (1982). Spatial descriptions and spatial continuity. Journal of Verbal Learning and Verbal Behavior, 21, 396-406.

Graesser, A. C. (1977). Sentence memory and comprehension. Unpublished doctoral dissertation, University of California, San Diego.

Guindon, R. & Kintsch, W. (1984). Priming macrostructures: Evidence for the primacy of macropropositions in the memory for text. Journal of Verbal Learning and Verbal Behavior, 23, 508-518.

Johnson-Laird, P. N. (1983). Mental models. Cambridge: Cambridge University Press.

Mani, K. & Johnson-Laird, P. N. (1982). The mental representation of spatial descriptions. Memory & Cognition, 10, 181-187 .

McKoon, G. & Ratcliff, R. (1981). The comprehension processes and memory structures involved in instrumental inference. Journal of Verbal Learning and Verbal Behavior, 20, 671-682.

McNamara, T. P., Ratcliff, R., & McKoon, G. (1984). The mental representation of knowledge acquired from maps. Journal of Experimental Psychology: Learning, Memory, and Cognition, 10, 723-732.

Meyer, D. E. & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. Journal of Experimental Psychology, 90, 227-234.

Ohlsson, S. (1984). Induced strategy shifts in spatial reasoning. Acta Psychologica, 57, 47-67.

Ratcliff, R. & McKoon, G. (1978). Priming in item recognition: Evidence for the propositional structure of sentences. Journal of Verbal Learning and Verbal Behavior, 17, 403-417.

Ratcliff, R. & McKoon, G. (1981). Automatic and strategic priming in recognition. Journal of Verbal Learning and Verbal Behavior, 20, 204-215.