Selecting One Among Many Referents in Spatial Situation Models

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Five experiments related anaphor resolution to a classic memory variable, namely, interference created by multiple uses of a given object-concept, and by spatial distance of the referent from the reader's focus of attention. Participants memorized a diagram of a building with rooms containing objects, and then read narratives describing characters' activities there. Reading was self-paced word by word. Accessibility was measured by readers' time to understand anaphoric sentences containing a definite noun phrase referring to an object in its room. Spatial distance between the object and the current focus of attention increased reading times for names of the object, the room, and sentence wrap-up. Multiple examples of a target-object increased its reading time only if they were scattered across different rooms. An associative model of memory retrieval during text comprehension was used to interpret the complex pattern of results.

Previous research has supported the general thesis that during narrative comprehension readers construct and make use of a mental model of the situation being described (Bower & Morrow, 1990; Rinck & Bower, 1995; Zwaan & Radvansky, 1998). The mental-model approach to discourse comprehension has been advanced by many cognitive scientists, including Bransford, Barclay, and Franks (1972); Garnham (1981); Glenberg, Meyer, and Lindem (1987); Johnson-Laird (1983); van Dijk and Kintsch (1983); and Zwaan and Radvansky (1998), to name but a few. The general idea is that readers use the text of a narrative to construct an internal model of the described situation in their working memory (Baddeley, 1986). The model includes the characters along with the locations of significant landmarks and the places in which the narrative actions occur. As narrative events unfold, readers update their mental model, moving characters from place to place, introducing new objects into the model or deleting old ones, and perhaps shifting attention to a new location or situation entirely. The model is used to interpret and evaluate incoming text statements—that is, to evaluate their plausibility and consistency with what went before—and to guide the inference process.

Much work has concentrated on how people update their current model as new information arrives, a process described by Zwaan and Radvansky (1998) as incorporating the current model into the integrated model. One line of research has examined how regularly readers update spatial relations during reading. The results of these studies suggest that readers are most likely to do so when they have the necessary spatial world knowledge and when it provides useful supports for comprehension (e.g., de Vega, 1995; Hakala, 1999; Zwaan, Radvansky, Hilliard, & Curiel, 1998). In a second line of research, the preconditions for spatial updating are maximized to study the effects of spatial updating on text comprehension. This is the research reported here, in which we have been especially interested in the role of the reader's mental focus in controlling this updating process. Specifically, we believe that readers update a bit of information by focusing their attention (internally) on that part of the model that is changing. For example, if the narrator moves the main character of the story from one place to another, the reader focuses on the main character, updates (changes) his or her current location, and remains focused for a while on that new location.

We have examined several consequences of this focus of attention within the reader's narrative model. Our basic procedure has participants first memorize the spatial layout of a building and later read stories about a character moving through the building in pursuit of some goal (e.g., looking for a lost notebook). We suppose that the reader's focus of attention is on this main character as the story describes his or her movements. A primary consequence of the reader's focus of attention is that known objects close within the model to the current focus become more activated in memory so that readers can readily refer to them or retrieve information about them to answer questions. For example, having moved the main story character into the bedroom, a reader will be much faster to answer that there is a radio in the bedroom. In studies conducted by Morrow and his colleagues (Morrow, Bower, & Greenspan, 1989; Morrow, Greenspan, & Bower, 1987), a distance gradient was found for this activation: The closer a probe object in the building was to the area where readers were currently focused, the faster they answered questions about the object. We have also found activation of (increased access to) objects and places along an implied (but unmentioned) path of movement through the building (Bower & Morrow, 1990). Thus,
The question that motivated the present experiments was whether a known "memory variable" would influence this referent lookup time in a predictable manner. The memory variable explored was the number of different objects in the referent room. The experimental manipulation required filling rooms of the building with varying numbers of distinct, unique objects; having the story refer to an object; and determining whether referent lookup time for that object increases with the number of objects in its room.

One hypothesis regarding this manipulation would treat retrieval of an object from any given room as a miniature "Sternberg list-scanning" task: The longer the list of objects in a given room, the longer on average it should take to retrieve and understand a reference to any one of them. Similarly, according to the "fan effect" (Anderson, 1974), retrieval of any given proposition (such as "The table is in the laboratory") is expected to be slower the more propositions are independently associated with any one of the entry concepts (such as laboratory). These hypotheses would therefore predict that readers will take longer to comprehend references to any unique object in a room as the number of other objects in the room is increased.

A different prediction follows from recent research by Radvansky and Zacks (1991) and Radvansky, Spieler, and Zacks (1993). They reported no fan effect as they varied the number of objects (over a small 1-4 range) that participants had memorized as placed in a single location. The authors proposed that, in such conditions, the collection of objects could be integrated into a single mental model and that retrieval of that "location model" was independent of how many objects had been memorized as located there. Thus, the Radvansky and Zacks view would predict that referent lookup time is independent of how many objects (within limits) are located in the room of the referent object. Experiments 1A and 1B were undertaken to distinguish between these two predictions.

**Experiment 1A: Object-Then-Room Anaphor With Many Types in One Room**

Participants first memorized a building layout (see Figure 1) having one, three, or five unique objects in each room. They then read stories word by word describing a character moving around the building. The main motion sentences moved the character (and the readers' presumed focus of attention) from a start ("source") room through an implied path room into a destination ("current location") room. While there, the character would "think about" some object located in one of these three rooms. The think-about sentence was of the form "Sandra thought about the computer in the laboratory," in which the object was mentioned before its room. We measured word-by-word reading time (with the participant-controlled RSVP method) to assess the effect of number of room objects on lookup time for the referent object before its room location was mentioned. We were also interested in examining "wrap-up" time at the end of each sentence, before the participant moved on to the next sentence: This end-of-sentence wrap-up time might also be sensitive to the speed and difficulty of calling up the referent object from memory (Haberlandt & Graeser, 1985, 1989). Across tests, the referent object was at varying distances from readers' current focus (location, path, or source room) to check that our tests were sensitive to the usual differential priming effects. We describe in detail only the method...
of Experiment 1A, because later experiments involved similar methods.

Method

Participants. Thirty-six psychology undergraduates at Stanford University participated in this experiment in exchange for course credit.

Layout learning. In the first part of the experiment, participants learned the layout of a research center containing nine rooms with a total of 27 objects. Three rooms contained only 1 object, another three rooms contained 3 objects, and three rooms contained 5 objects. Figure 1 displays one of the six sample layouts used in Experiment 1A. Participants studied the layout for 1 min, turned it over, and were given a blank diagram containing only the walls and doors of the building. They were asked to recall by writing all of the room names and object names they could remember at their correct locations on the diagram. They then compared their recall with the original layout and noted errors. Any errors occasioned further study and tests on the map. Participants proceeded through such self-paced study-test cycles until they could perfectly reproduce all room and object names in their correct locations. They then answered 11 questions about locations of rooms and objects in the building. Participants required approximately 30 min to learn the layout and answer the questions perfectly.

In each of the nine rooms of the learned building, one object was the critical target object to be referred to during the second part of the experiment. As a means of enhancing the comparability of the results, these nine target objects (telephone, lamp, table, calendar, computer, chair, poster, mirror, and clock) were identical in all of the experiments reported here. Also, these target objects were chosen because they could plausibly be located in any of the nine rooms of the building. To counterbalance the materials and experimental conditions, we used six different versions of the layout, each learned by 6 participants. These layout versions differed in the way the three different number-of-objects conditions were distributed over the nine rooms of the building.

Narrative reading. Having memorized the building map, participants proceeded to the second part of the experiment in which they read 15 narratives (1 practice narrative followed by 14 experimental narratives) presented one word at a time on the screen of an Apple Macintosh computer controlled by the RSVP software (Williams & Tarr, n.d.). The only exception to this single word-by-word presentation mode was room names consisting of two words (e.g., "storage room"), which were presented together as one unit. Presentation of the words was self-paced; each word was presented in the center of the computer screen, and participants pressed the button of the computer's mouse to advance from one word to the next. The last word of each sentence also contained the end-of-sentence punctuation. A button press to the last word brought on a blank screen that served as a break between sentences; another button press brought on the first word of the next sentence. The blank screens were presented to allow measurement of sentence wrap-up processes. Also, pilot tests had revealed that participants found reading without the blank screen very irritating, presumably because immediate presentation of the first word of the next sentence prevents wrap-up processes. Time between every two successive button presses was recorded and taken to be an estimate of comprehension time for the word exposed for that duration. Participants were free to hold the mouse in the hand they preferred and to change hands between stories to avoid fatigue.

An example of the experimental narratives used in Experiment 1A is given in the Appendix. Each narrative was approximately 20 sentences long and described the actions of a protagonist who moved through the building trying to achieve some goal, such as searching for lost lecture...
notes. At the end of each narrative, three yes-no questions were presented (as complete sentences) to test comprehension of the narrative. These questions queried such details as the reason for certain actions, the location of certain activities, and the order of actions (see Appendix). The 36 participants had an average error rate of 8% on these questions (range: 2% to 18%). Participants answered yes or no to each question by pressing either the Y key or the N key of the computer’s keyboard. They were free to use either hand and any finger to press these keys, because question answering time was not critical to our results. Participants were instructed to read carefully but at their natural speed. Word reading times, as well as question answering times and correctness of answers, were recorded by the computer.

Distributed over the 14 experimental narratives, 27 blocks of critical sentences were presented to the participants. All blocks consisted of a motion sentence, a coherence sentence, and an anaphoric target sentence. Each motion sentence described a complete motion event in which the protagonist walked from one room (source room) through an unmentioned but implied room (path room) into the next room (location room). Examples are given in the Appendix and Figure 1 (“She walked from the library into the storage room”). After each motion sentence, a coherence sentence was presented to motivate the mental event that was to be described in the following critical anaphoronic sentence (e.g., “She tried to remember where she had left her notes that morning by mentally retracing her steps,” see Appendix). Earlier work showed that such coherence sentences help smooth the transition between the motion sentence and the mental-event target sentence that follows (see Rinck & Bower, 1995). The coherence sentence was followed by an anaphoric target sentence containing a definite noun phrase that referred to one of the unique target objects in one of the rooms of the research center (e.g., “She remembered that she had been standing in front of the chair in the storage room earlier that day”). As the Appendix illustrates, this object could be situated in the location room (e.g., the chair in the storage room), the path room (e.g., the computer in the laboratory), or the source room (e.g., the calendar in the library). All anaphoric sentences described some type of mental event, such as thinking about, remembering, or deciding about some aspect of the referent object. Each anaphoric sentence contained the name of the target object referred to, followed by the name of the target room (e.g., the chair in the storage room). In the following, we refer to these as object–room sentences.

By presenting one of the three different versions of the target sentence, we varied the type of target room. The number of objects located in the target room was varied by having each participant study one of the six different layout versions described earlier. For instance, for participants who studied the layout depicted in Figure 1, the lounge contained the critical target object, namely, mirror, and two additional objects, namely, television and refrigerator. For other participants, five objects were located in the lounge: mirror, television, refrigerator, bed, and coke machine. For the third group of participants, the lounge contained only the critical target object (i.e., the mirror). Additional objects were never referred to in the target sentences. To prevent participants from forgetting the additional objects during the course of the experiment, we included additional object sentences as control sentences in the narratives (see Appendix). For instance, participants who had learned the layout depicted in Figure 1 read the first additional sentence shown in the Appendix (“She looked nervously around and checked every possible place behind the television and even in the refrigerator”). Participants who had learned a layout version with five objects located in the lounge read the second additional sentence shown in the Appendix (“She looked nervously around and checked every possible place behind the television, under the bed and the coke machine, and even in the refrigerator”). Finally, neither sentence was presented to participants who had learned that the lounge contained only the target object.

Each participant read 27 critical anaphoric sentences, that is, 3 sentences in each experimental condition, as defined by the full combination of target room type (location room, path room, or source room) and number of objects in the target room (one, three, or five). For any given narrative, each participant read only 1 of the 3 possible anaphoric sentences. As a means of counterbalancing materials and experimental conditions, the 14 experimental narratives were divided into three sets of materials, and each set was presented to 12 participants. In addition, six different layouts were used, each studied by 6 participants. Narrative sets and layout versions were completely crossed. After reading all 15 narratives, the participants completed a short questionnaire about their reading strategies and features of the narratives, and they were debriefed. They required about 45 min to read the narratives and answer the questions.

Design. Full combination of the target room type (location, path, or source) and number of objects (one, three, or five) variables yielded a 3 × 3 design. Both variables were varied within subjects. The dependent variables of interest were the reading times of the object names and the room names contained in the anaphoric target sentences. In addition, presentation times of the blank screen following the last word of each target sentence were analyzed as an index of sentence wrap-up time.

Results

Reading times of the words contained in the anaphoric sentences were analyzed after outliers (5% of the reading times) had been excluded from the data. Outliers were determined separately for each dependent variable and relative to each participant and each experimental condition. First, difference scores were computed by subtracting each participant’s median reading time from his or her overall reading times. Then, separately for each dependent variable and each experimental condition, the upper and lower 2.5% of difference scores were determined, and the corresponding reading times were marked as outliers and replaced by the participant’s median reading time (Rinck, 1994). All analyses were computed twice, once with the 36 participants as a random variable and once with the 27 anaphoric sentence positions. Values are shown for by-participants analyses ($F_p$) and by-materials analyses ($F_m$). The reading times observed in the subsequent experiments were treated the same way.

Object names. Reading times of the object names contained in the anaphoric target sentences are shown in the upper part of Table 1. Reading times of these words increased with increasing distance in the mental map between the object denoted by the word and the current location of the protagonist. This spatial gradient of accessibility was reflected by a significant effect of target room type, $F_p(2, 70) = 15.72, p < .001, F_m(2, 52) = 23.44, p < .001$. In addition, planned comparisons revealed that reading times of objects located in the location room were shorter than those of objects located in the path room, $F_p(1, 35) = 9.52, p < .01, F_m(1, 26) = 13.60, p < .01$, which in turn were shorter than those of objects located in the source room, $F_p(1, 35) = 6.04, p < .05, F_m(1, 26) = 7.25, p < .05$. The number of objects located in the target room, however, had no effect on the accessibility of the target object (both $F_s < 1$). The interaction of target room type and number of objects was also not significant (both $F_s < 1$).

Room names. Reading times of the room names contained in the anaphoric target sentences are depicted in the middle part of Table 1. The pattern of results observed for these reading times was very similar to that for the object names. Again, a significant effect of target room type indicated a spatial gradient of accessibility, $F_p(2, 70) = 24.46, p < .001, F_m(2, 52) = 19.63, p < .001$; reading times of objects located in the location room were shorter than those of objects located in the path room, $F_p(1, 35) = 19.30, p < .001, F_m(1, 26) = 14.90, p < .01$, which in turn were shorter...
than those of objects located in the source room, $F_1(1, 35) = 6.59, p < .05$, $F_2(1, 26) = 4.26, p < .05$. Again, neither the number of objects located in the target room (both $F$s < 1.71, ns) nor the interaction was significant (both $Fs < 1$).

Blank screens. The lower part of Table 1 shows the presentation times of the blank screen following each anaphoric target sentence. These presentation times presumably reflect the final sentence wrap-up processes. Again, a significant effect of target room type was observed, $F_1(2, 70) = 7.96, p < .01$, $F_2(2, 52) = 13.62, p < .001$. References to objects in the location room yielded shorter presentation times than references to objects in the path room, $F_1(1, 35) = 11.96, p < .01$, $F_2(1, 26) = 20.16, p < .001$. The latter, however, did not differ significantly from references to objects in the source room (both $Fs < 1$). As before, neither the number of objects located in the target room (both $F$s < 1) nor the interaction was significant (both $Fs < 1$).

Discussion

Taken together, the reading times observed in this experiment yielded a very clear pattern of results. For object names, room names, and blank screens alike, spatial distance from the focus of attention affected reading times, yielding a spatial gradient of accessibility. This result has both methodological and theoretical implications. First, it indicates that word-by-word reading tasks can be used successfully to investigate effects of spatial situation models on the accessibility of situation model components, in this case referents for single anaphoric nouns or noun phrases. Second, the fact that spatial distance affected reading times of the object name suggests that readers did indeed retrieve the referent of the anaphoric expression on encountering the object name. This result supports the "immediacy" assumption of Just and Carpenter (1980), namely, that the duration of a fixation on a word reflects the time to look up the memory entity or referent of that word before moving on to the next word in the sentence. However, we also observed an effect (although somewhat weaker) of spatial distance on time taken on the blank screen following each sentence. This latter result indicates that some processing of the anaphoric noun phrases persisted into the wrap-up period for the target sentence (Haberlandt & Graesser, 1985, 1989). The spatial gradient in reading times of room names presumably reflects the differing accessibility of these rooms at varying distances from the focus. In contrast to the clear-cut effect of spatial distance, the number of objects located in the target room had no effect whatsoever. Whether there were zero, two, or four additional objects located in the target room, accessibility of the target object was not affected. Before we discuss the theoretical implications of this finding, we report the results of Experiment 1B, which investigated a critical linguistic variant.

<table>
<thead>
<tr>
<th>Word type and number of different objects in room</th>
<th>Location room</th>
<th>Path room</th>
<th>Source room</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
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<td>Object name</td>
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</tr>
</tbody>
</table>

Table 1

*Mean Reading Times, in Milliseconds, Observed in Experiment 1A*

In the referring expressions in the target sentences of Experiment 1A, the object name always preceded the room name (e.g., "She remembered that she had been standing in front of the chair in the storage room"). Because the chair is a unique object in the building and it was encountered in reading the sentence before the room name, there may have been no opportunity for the number of memorized objects in the referent room to create interference in retrieving the chair entity in the model. Perhaps finding an effect of number of objects requires that the room name occurs first, before the object name, so that the multiplicity of possible referents in that room can be activated (to interfere with retrieval of the specific object mentioned a few words later). That is, in the phrase "She remembered that she had been standing in the storage room in front of the chair," the storage room may quickly call to mind the two or four other objects there in addition to the chair, and these fleeting contents might slow down identification of the chair referent in the model when the word chair occurs later. If this were so, then the word-by-word reading method should show an effect of number of room objects on time to read the room name, the object name, or both.

Experiment 1B: Room-Then-Object Anaphor

With Many Types in One Room

In the referring expressions in the target sentences of Experiment 1A, the object name always preceded the room name (e.g., "She remembered that she had been standing in front of the chair in the storage room"). Because the chair is a unique object in the building and it was encountered in reading the sentence before the room name, there may have been no opportunity for the number of memorized objects in the referent room to create interference in retrieving the chair entity in the model. Perhaps finding an effect of number of objects requires that the room name occurs first, before the object name, so that the multiplicity of possible referents in that room can be activated (to interfere with retrieval of the specific object mentioned a few words later). That is, in the phrase "She remembered that she had been standing in the storage room in front of the chair," the storage room may quickly call to mind the two or four other objects there in addition to the chair, and these fleeting contents might slow down identification of the chair referent in the model when the word chair occurs later. If this were so, then the word-by-word reading method should show an effect of number of room objects on time to read the room name, the object name, or both.

Experiment 1B was essentially a replication of Experiment 1A (with referents in the source, path, and location rooms), except that the critical referring sentences were rewritten so that the room name came a few words before the object name. The question is whether this change in order of room and object names produces
an effect of number of room objects in addition to the usual spatial distance gradient in referent lookup time.

Method

Participants. Thirty-six psychology undergraduates at Stanford University participated in this experiment, compensated by course credit. None of them had participated in Experiment 1A.

Layout learning and narrative reading. The layouts used in this experiment were identical to those of the first experiment. The narratives were nearly identical to those of Experiment 1A. The only difference occurred in the anaphoric target sentences, in which the order of the object name and the room name was reversed. To illustrate, consider the two object–room target sentences depicted in the Appendix: “She remembered that she had been standing in front of the chair in the storage room earlier that day” and “She recalled that in the morning, she had eaten something in the office.” These sentences were changed into the corresponding room–object sentences “She remembered that she had been standing in front of the chair in the storage room” and “She recalled that in the morning, she had eaten something in the phone while looking at the phone.”

Design. The experimental design was identical to that of the first experiment.

Results

Object names. The upper part of Table 2 shows the reading times of the object names contained in the anaphoric target sentences. As in Experiment 1A, reading times of these words increased with increasing distance between the object and the current location of the protagonist, F1(2, 70) = 9.44, p < .001, F2(2, 52) = 13.10, p < .001. Planned comparisons revealed that reading times of objects located in the location room were shorter than those of objects located in the path room, F1(1, 35) = 7.30, p < .05, F2(1, 26) = 12.86, p < .01, which in turn tended to be shorter than those of objects in the source room, F1(1, 35) = 2.68, p < .12, F2(1, 26) = 3.30, p < .10. However, contrary to expectations, the number of objects located in the target room had no effect on the accessibility of the target object (both Fs < 1) nor the interaction was significant (both Fs < 1).

Room names. Reading times of the room names contained in the anaphoric target sentences are depicted in the middle part of Table 2. The pattern of results observed for these reading times resembled that of the first experiment. Again, a significant effect of target room type indicated a spatial gradient of accessibility, F1(2, 70) = 15.94, p < .001, F2(2, 52) = 7.93, p < .01; reading times of objects in the location room were shorter than those of objects in the path room, F1(1, 35) = 12.58, p < .01, F2(1, 26) = 4.71, p < .05, which in turn tended to be shorter than those of objects in the source room, F1(1, 35) = 5.68, p < .05, F2(1, 26) = 4.06, p < .10. Again, neither the number of objects located in the target room (both Fs < 1) nor the interaction reached statistical significance (both Fs < 1).

Blank screens. The lower part of Table 2 shows the presentation times of the blank screens following the anaphoric target sentences. As before, a significant—although somewhat weaker—effect of target room type was observed with these presentation times, F1(2, 70) = 3.37, p < .05, F2(2, 52) = 3.41, p < .05. References to objects in the location room tended to yield shorter presentation times than references to objects in the path room, F1(1, 35) = 3.35, p < .10, F2(1, 26) = 2.10, p < .16. The latter did not differ significantly from references to objects in the source room (both Fs < 1.54, ns). Again, neither the number of objects located in the target room (both Fs < 1) nor the interaction was significant (both Fs < 1).

Discussion

In two experiments varying the number of room objects from one to three and five, we found no effect of this variable on the time participants took to read a phrase referring to one of those objects. This null effect occurred whether the referring phrase mentioned the object first or the room first. The null result cannot be attributed to low power of the experiment, because the standard result of a spatial gradient on referent reading time came through in its usual robust fashion (e.g., Rinck & Bower, 1995). This result clearly upsets expectations based on the idea that referent lookup involves memory retrieval combined with the fan effect principle of memory retrieval enunciated by Anderson (1974, 1983).

<table>
<thead>
<tr>
<th>Target room type</th>
<th>Location room</th>
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<th>Source room</th>
</tr>
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<tr>
<td>Word type and number of different objects in room</td>
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<tr>
<td>Object name</td>
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</table>
The absence of an effect of number of room objects is compatible with the proposal of Radvansky and Zacks (1991) and Radvansky et al. (1993). Their claim is that when participants have memorized a collection of one to four small objects located in a single spatial scenario, time to retrieve and verify the presence of any one of these objects is independent of their number in the scenario. Radvansky and his colleagues found this null effect when participants learned the materials from sentences, although the result now appears to hold as well when the learning materials are spatial diagrams of objects in rooms, as was the case here. Radvansky et al. also found this null effect of number of objects when the learning and testing materials were of the alternate forms “The pay phone is in the hotel” and “In the hotel is the pay phone.” This variation in order of object and location names mimics the variation we examined in our two experiments and yielded analogous null results on referent lookup time.

Anderson and Reder (1999) have engaged in discussions with Radvansky (1999) in an attempt to characterize the conditions under which a fan effect will be evidenced in memory retrieval latencies. We do not attempt to adjudicate their differences here, but we take from this a result on which the parties agree: If different examples (tokens) of the same type of object are placed in different locations or scenarios, then the time to retrieve a memory to verify a statement about any one of them will increase with the number of tokens. For instance, if participants learn that there are five tables located in five different rooms of a building, three lamps located in three different rooms, and one telephone located in one room, then the time for participants to read a reference to some object should increase with the number of examples of that object that have been learned.

Experiment 2A: Object-Then-Room Anaphor With Many Tokens in Different Rooms

Experiment 2A was carried out to test this prediction regarding the influence of number of examples of given object types. The maps and stories were altered so as to create one, three, or five instances of critical objects that would be the targets of referring sentences. Each room had exactly three objects, but the number of instances of different object types was varied (see Figure 2). In Experiment 2A, the referring expression was of the form “the object in the room,” whereas the order of the room and object name was reversed for the narratives in Experiment 2B. Otherwise, the general procedure, including counterbalancing of tested objects, rooms, and distances, was as in the earlier experiments.

Method

Participants. Thirty-six psychology undergraduates at Stanford University participated in this experiment, compensated by course credit or a $10 payment. None had participated in the previous experiments.

Layout learning and narrative reading. The layouts used in this experiment differed from those of the first two experiments. A sample layout is depicted in Figure 2. As before, each layout of the research center contained nine rooms and a total of 27 objects. However, the number of objects located in each room was held constant at 3, whereas the number of objects of a particular type was varied. For instance, different layouts
contained one table, three tables, or five tables. Different versions of the layout were presented to different participants to ensure full combinations of experimental conditions and materials. The sample layout depicted in Figure 2 illustrates the layout shown to a particular group of participants. These participants, for instance, learned a diagram that located one phone, calendar, and poster in different rooms; three lamps, mirrors, and computers in three different rooms; and five tables, clocks, and chairs in five different rooms.

The procedures for learning the layouts and reading the narratives were identical to those of the previous experiments. The anaphoric target sentences were identical to those of the previous experiments. The anaphoric target sentences were identical to those of the previous experiments. The anaphoric target sentences were identical to those of the previous experiments. The anaphoric target sentences were identical to those of the previous experiments.

In the case of multiple objects, the target sentence always referred to the target object, not to the additional objects of the same type. In addition, a manipulation check on layout recall was introduced in Experiment 2A.

After participants had finished reading the narratives, they were asked to draw the learned layout from memory on a blank sheet of paper. These postexperimental drawings were practically perfect, indicating that participants still knew the rooms and the locations of the objects by the end of the experiment. The same was true for the following experiments.

**Design.** Full combination of target room type (location, path, or source) and number of objects across rooms (one, three, or five) yielded a 3 × 3 design. Both variables were varied within subjects. Again, the dependent variables of interest were the reading times of the object names and the room names contained in the anaphoric target sentences as well as the time spent pausing on the blank screen after the last word of each target sentence.

**Results**

**Object names.** The upper part of Table 3 presents the reading times of the object names contained in the anaphoric target sentences. In contrast to the earlier experiments, number of examples of an object type significantly affected reading times of these words, $F_{(2, 70)} = 19.32, p < .001$, $F_{(2, 52)} = 24.51, p < .001$. Reading times increased with increasing number of examples of a type of object scattered across different rooms of the building. Planned comparisons revealed that names of single objects were read faster than names of objects that occurred in three different rooms, $F_{(1, 35)} = 9.86, p < .01$, $F_{(1, 26)} = 12.29, p < .01$. These in turn were read faster than names of objects that occurred in five different rooms, $F_{(1, 35)} = 10.56, p < .01$, $F_{(1, 26)} = 14.08, p < .01$. Target room type had no significant effect on reading time for the object name (both $F$s < 1); this was expected because the room was not specified until after the object name had been encountered. The interaction of number of objects and room type was also insignificant (both $F$s < 1).

**Room names.** Reading times of the room names contained in the anaphoric target sentences are depicted in the middle part of Table 3. These reading times resembled those of the first experiments. Again, a significant effect of target room type indicated a spatial gradient of accessibility, $F_{(2, 70)} = 5.33, p < .01$, $F_{(2, 52)} = 4.11, p < .05$; reading times of objects in the location room were shorter than those of objects in the path room, $F_{(1, 35)} = 5.87, p < .05$, $F_{(1, 26)} = 4.17, p < .10$, although the latter did not differ significantly from reading times for objects in the source room (both $F$s < 1). As expected, the number of tokens associated with the object types located in the target room had no significant effect (both $F$s < 1), nor did the interaction of number of tokens and target room type (both $F$s < 1).

**Blank screens.** The lower part of Table 3 shows the average pause times on the blank screens following the anaphoric target sentences. As before, they showed a weak effect of target room type, $F_{(2, 70)} = 4.81, p < .05$, $F_{(2, 52)} = 2.65, p < .10$. References to objects in the location room tended to yield shorter presentation times than references to objects in the path room, $F_{(1, 35)} = 4.80, p < .05$, $F_{(1, 26)} = 2.33, ns$. The latter did not differ significantly from references to objects in the source room (both $F$s < 1, ns). Again, neither the number of associated tokens of objects located in the target room (both $F$s < 1) nor the interaction was significant (both $F$s < 1).

**Discussion**

Experiment 2A has finally unearthed the sought-after fan effect in anaphor lookup time: The more tokens of a given object type scattered around different rooms of the building, the longer readers dwelt on that target object name while reading. Appropriately, these results for object-name reading arose when the object name preceded the room name, that is, before the particular object token being referred to was specified by the following room phrase.

<table>
<thead>
<tr>
<th>Word type and number of identical objects across rooms</th>
<th>Location room</th>
<th>Path room</th>
<th>Source room</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Object name</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 object</td>
<td>176</td>
<td>76</td>
<td>170</td>
</tr>
<tr>
<td>3 objects</td>
<td>189</td>
<td>64</td>
<td>190</td>
</tr>
<tr>
<td>5 objects</td>
<td>214</td>
<td>78</td>
<td>206</td>
</tr>
<tr>
<td><strong>Room name</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 object</td>
<td>176</td>
<td>84</td>
<td>192</td>
</tr>
<tr>
<td>3 objects</td>
<td>183</td>
<td>102</td>
<td>205</td>
</tr>
<tr>
<td>5 objects</td>
<td>188</td>
<td>74</td>
<td>209</td>
</tr>
<tr>
<td><strong>Blank screen</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 object</td>
<td>204</td>
<td>130</td>
<td>221</td>
</tr>
<tr>
<td>3 objects</td>
<td>201</td>
<td>131</td>
<td>216</td>
</tr>
<tr>
<td>5 objects</td>
<td>203</td>
<td>131</td>
<td>220</td>
</tr>
</tbody>
</table>
This longer time might reflect one of several processes. One possibility is that readers dwell on a word type until they have retrieved some particular referent entity for it, and they take longer to retrieve any one token when activation (or retrieval energy) from the object-type node in memory is divided and diluted among the one, three, or five tokens in memory. This view implies that readers commit themselves to a particular referent in reading an ambiguous expression even though specifying information is not yet available. This view would predict that when participants encounter the later room name that uniquely specifies the referent, with probability \((R - 1)/R\) (where \(R = 1, 3, \text{or} 5\)) they have to backup, discard the referent they had bet on earlier, and replace it with the correct referent specified by the room name. This process implies that the following room name would be read more slowly (as a result of backup) the greater the number of tokens of each type. This prediction was decidedly not confirmed; number of object tokens preceding a room name was found to have no effect on time to read the room name.

A second possibility is that readers have an immediate awareness that the object name refers to one versus more than one possible referent. We may suppose that the more possible referents, the greater would be the readers' sense of uncertainty regarding the intended referent and, therefore, the more time they would take to move on to the next word. This view supposes that readers partially activate all of the tokens of the object type but postpone selection of any particular referent until the specifying room information is provided and that the time to perform this final selection is independent of how many memory tokens have been partially activated.

In contrast to the object reading times, the location of the token in the upcoming target room (source, path, or location) had no influence on object reading times. This outcome is consistent with the second hypothesis mentioned earlier, namely, readers do not retrieve any particular token until the room type is mentioned, thus avoiding backup processing. The lack of an effect of distance to the to-be-specified token is understandable in that other, unreferenced tokens can be at randomly varying distances from the focus on the character. For example, there might be several other examples of that object type in rooms that could be as close to the focus as is the target example.

As before, speed of reading the room name showed the standard "distance" gradient, with the location room being fastest and the source room slowest. These room reading times were unaffected by the number of tokens of the referent example, presumably because readers did not commit themselves to a particular referent token that had to be replaced when the room name was mentioned later in the sentence.

Experiment 2B: Room-Then-Object Anaphor
With Many Tokens in Different Rooms

If the explanation of the results observed in Experiment 2A is correct, they depend very much on the order in which the object name and the room name are mentioned in the target sentence (viz., object before room). The crucial importance of this order was tested next by using the reverse, room–object order of mention in the target sentences of Experiment 2B. If room names are mentioned first, their reading times should depend only on the type of target room, reflecting the usual spatial gradient of accessibility, but room reading time should not depend on the multiplicity of the examples in that room. Because no object name has yet been encountered in the sentence, the number of tokens of the target object type (mentioned later) should not affect reading time of the room name. In contrast, reading time of the later object name should be affected by its number of tokens (the fan effect) and possibly by room type, with target tokens in closer rooms being retrieved faster. The latter effect would arise if objects closer to the focus were more activated, thus facilitating the linking up of the appropriate one of these referents to the target object type that is mentioned later in the sentence. Experiment 2B was carried out to search for these effects on word reading time.

Method

Participants. Thirty-six psychology undergraduates at Stanford University participated in this experiment, compensated by course credit or a $10 payment. None had participated in the previous experiments.

Layout learning, narrative reading, and design. Experiment 2B was identical to Experiment 2A except for the anaphoric target sentences. As in Experiment 1B, room–object sentences were used.

Results

Object names. The upper part of Table 4 presents the reading times of the object names contained in the anaphoric target sentences. In this experiment, reading times of the object names were affected by both target room type, \(F_1(2, 70) = 12.21, p < .001, F_2(2, 52) = 8.43, p < .01\) and the number of objects across rooms, \(F_1(2, 70) = 6.39, p < .01, F_2(2, 52) = 7.71, p < .01\). Object reading times increased with increasing number of objects across the rooms of the building; names of single objects were read faster than names of objects that occurred in three different rooms, \(F_1(1, 35) = 9.17, p < .01, F_2(1, 26) = 12.35, p < .01\). The latter times did not differ from those for objects that occurred in five different rooms (both \(Fs < 1\)). A similar result was observed for target room type; reading times of an object name referring to an object in the location room were shorter than those of object names whose referent was located in the path room, \(F_1(1, 35) = 18.22, p < .001, F_2(1, 26) = 10.94, p < .01\) but the latter did not differ significantly from the time to read an object name whose referent was located in the source room (both \(Fs < 1\)). As in the previous experiments, the interaction of target room type and number of objects was not significant, \(F_1(4, 140) = 1.89, ns, F_2(4, 104) = 1.31, ns\).

Room names. Reading times of the room names contained in the anaphoric target sentences are shown in the middle part of Table 4. As in the previous experiments, neither the number of tokens of the following object type nor the interaction reached statistical significance (both \(Fs < 1\)), whereas target room type did produce significant effects, \(F_1(2, 70) = 12.72, p < .001, F_2(2, 52) = 8.20, p < .01\). Although reading times of the location room name were shorter than those for the path room name, \(F_1(1, 35) = 14.49, p < .01, F_2(1, 26) = 8.88, p < .01\), the latter was not significantly shorter than the time to read the name of the source room, \(F_1(1, 35) = 1.99, ns, F_2(1, 26) = 1.53, ns\).

Blank screens. The lower part of Table 4 shows the pause times on the blank screens following the anaphoric target sen-
tences. As before, they were affected only by target room type, $F_1(2, 70) = 5.86, p < .01, F_2(2, 52) = 3.34, p < .05$. References to objects in the location room tended to yield shorter wrap-up times than references to objects in the path room, $F_1(1, 35) = 5.81, p < .05, F_2(1, 26) = 3.11, p < .10$. The latter did not differ significantly from references to objects in the source room, $F_1(1, 35) = 1.17, ns, F_2(1, 26) < 1$. Again, neither the number of tokens of object types (both $F$s < 1) nor the interaction was significant (both $F$s < 1).

**Discussion**

The results are rather much as predicted for time to read referring expressions containing the room name before the object name. Greater distance of the room from the protagonist focus slowed down the time to read that room name, whereas the multiplicity of the upcoming object name did not act forward in time to affect this room-reading time. On the other hand, reading time for the following object name showed both effects strongly, that is, faster retrieval of object referents that were fewer in number and closer to the protagonist. These variables did not interact, nor was any interaction expected.

Experiment 3: Varying Number of Object Examples in Room and Object–Room Sentences

Experiments 2A and 2B revealed a fan effect for reading times of object names, whereas Experiments 1A and 1B did not. We attribute this difference to the fact that Experiments 2A and 2B involved a fan of objects across rooms; in the case of three or five objects of the same kind (e.g., three or five tables), these objects were located in different rooms. However, number of tokens of an object type and number of rooms involved are obviously confounded in the comparison of these experiments: They differ in the type of fan (number of objects in the target room vs. number of objects across rooms) as well as in the number of rooms involved (always one room vs. one, three, or five rooms). Thus, number of objects and number of rooms were confounded in Experiments 2A and 2B.

Another confound inherent in Experiments 2A and 2B arises because participants had to encode and remember the locations of one, three, or five tokens of the different object types, so that more tokens undoubtedly required a more detailed memory structure with more opportunities for interference (which tokens go where?) than was the case in Experiments 1A and 1B. Conceivably, it was this inherently greater interference and memory load that gave rise to the observed differences in object retrieval times in Experiments 2A and 2B. Thus, differences in the degree of initial learning rather than differences in the ease of referent lookup during reading might cause the observed effects.

Experiment 3 was conducted to equate conditions for this memory load factor while varying the number of tokens learned and to unconfound the number of tokens versus the number of rooms in which they were located. These goals were achieved by simply placing all of the tokens of one object type in the same room. For instance, for a given participant's map, regardless of whether there were one, three, or five tables, they were always located in the conference room, and no other objects were ever located in this room (see Figure 3). Thus, the number of objects of a particular type was identical to the number of objects located in the target room, whereas the number of objects in each room varied among one, three, and five, just as in Experiments 1A and 1B. If it is overall memory load created by scattering multiple tokens across multiple rooms that is causing the slowdown due to number of tokens, then the maps of Experiment 3 (all tokens of the same type in one room) should be easier to learn and should promote faster reading of referring expressions independent of the number of tokens. On the other hand, if the number of objects of a particular type is sufficient to create the fan effect, it should be observed in this case of redundant locations as well. If it is crucial that the object tokens are located in different rooms, the fan effect should not
occur here. Experiment 3 was directly comparable to Experiments 1A and 2A in using only object–room target sentences.

**Method**

**Participants.** Thirty-six psychology undergraduates at Stanford University participated in this experiment, compensated by course credit or a $10 payment. None had participated in the previous experiments.

**Layout learning, narrative reading, and design.** The layouts used in this experiment were different from those of the other experiments. A sample layout is depicted in Figure 3. As before, each layout of the research center contained nine rooms and a total of 27 objects. However, each room contained one, three, or five tokens of the same object type. Thus, unlike in Experiments 2A and 2B, multiple objects of the same type were not spread out across different rooms; rather, they were all located in the same room. Again, different versions of the layout were presented to different participants to ensure a full combination of experimental conditions and materials. The sample layout depicted in Figure 3 illustrates the layout shown to a particular group of participants. These participants, for instance, studied a single telephone located in the office, three lamps in the reception room, and five small tables in the conference room.

The procedures involved in learning the layouts and reading the narratives as well as the experimental design were identical to those of the previous experiments. As in Experiments 1A and 2A, object–room target sentences were used in Experiment 3. A minor stylistic variation was introduced in these sentences to ensure easy comprehension. Depending on the number of objects in a given room, the target object was referred to via the definite article the (for one-token referents) or the indefinite article a or an (for multitoken referents). For instance, participants who had studied a single phone in the office would read about "the phone," whereas "a phone" was used for participants who had studied three or five phones in the office. In line with the results of Radvansky et al. (1993), we did not expect an effect of this variation in article type. Otherwise, the anaphoric target sentences were identical to the object–room sentences used before. The experimental design was identical to those of the first two experiments, with the "number of objects" variable referring to the number of objects located in the same room.

**Results**

**Object names.** The upper part of Table 5 presents the reading times of the object names contained in the anaphoric target sentences. They mirrored those of Experiments 1A and 1B. Reading times of these words increased only with increasing distance between the object and the current location of the protagonist, yielding only a significant effect of target room type, $F_1(2, 70) = 10.16, p < .001, F_2(2, 52) = 7.98, p < .01$. The number of tokens of an object type located in the target room had no effect on reading time of the target word (both $F$s < 1). Also, the interaction of target room type and number of objects was not significant (both $F$s < 1.16, ns).

**Room names.** Reading times of the room names contained in the anaphoric target sentences are depicted in the middle part of Table 5. Just as with the object names, reading times of the room names were affected solely by target room type, $F_1(2, 70) = 6.25, p < .01, F_2(2, 52) = 3.65, p < .05$. Neither the number of objects in a room (both $F$s < 1) nor the interaction, $F_1(4, 140) = 1.79, ns, F_2(4, 104) < 1$, yielded significant effects.
Blanks screens. The lower part of Table 5 shows the pausing times on the blank screens following the anaphoric target sentences. These presentation times revealed a very weak, insignificant effect of number of objects, $F_1(2, 70) = 3.09, p < .10, F_2(2, 52) = 1.44, ns$; a strong, significant effect of target room type, $F_1(2, 70) = 5.16, p < .01, F_2(2, 52) = 4.20, p < .05$; and no effect of the interaction, $F_1(4, 140) = 2.41, p < .10, F_2(4, 104) = 1.66, ns$.

Discussion

The results of Experiment 3 are quite clear: Spatial distance from focus caused the usual slowing in time to read the room name and the object name, whereas the number of tokens of a given object type had no influence on reading time for either word. The absence of influence of number of tokens on object reading time in this experiment contrasts with the slowing of reading time due to number of object tokens in Experiment 2A. Presumably, the slowing in Experiment 2A was caused by the ambiguity regarding which referent (in which room) the object name was intended to pick out. The attendant uncertainty was alleged to cause the slower reading time for this object name. In contrast, in Experiment 3, although the exact token is not yet specified by the object name, there is no ambiguity about which room is its location. Because all tokens of a given object type were placed in the same room, the object name carried immediate knowledge of the room–location of the referent. Moreover, whenever multiple tokens existed, the narration involved indefinite noun phrases (e.g., a telephone or a clock), so participants must have realized that any one of the token objects in that room would suffice for understanding the narrator’s referent. Thus, the target object words in Experiment 3 never created uncertainty about which referent to choose for comprehension. Because all tokens of a given type were in the same room, they were all activated to a greater or lesser degree depending on the distance of that room from the focus, which explains why room distance influenced object reading time in Experiment 3 but not in Experiment 2A.

Presumably, the effect of number of tokens on object reading time would reappear if the story used definite referring expressions that required readers to select specific tokens by their relative location within the room. Example expressions would be “the clock next to the coffee urn,” “the lamp beside the sofa,” and “the table against the right-hand wall.” This procedure would be analogous to creating sublocations within each room, which then would serve much like the rooms did in Experiments 1A and 2A. Our hypothesis would predict that, in such cases, time to read the object name should increase with the number of tokens, despite their all residing in the same room. This prediction involves the same uncertainty principle used in explaining the results of Experiments 2A and 2B: Because the narrator will later be instructing readers to pick out and focus on a specific token, the object name alone is ambiguous (creating uncertainty) until further information comes along later in the sentence to specify the exact referent token within the room.

General Discussion

As indicated in the introduction, these experiments began with the assumption that during language comprehension referent lookup can be treated as a memory retrieval process. We investigated whether this was so especially for cases in which the domain of discourse included places and things highly familiar to the readers. To this end, we have examined word-by-word reading times with the assumption that a word’s reading time (or comprehension time) reflects in part a referent lookup process.

In accounting for the present results, the general theoretical framework that has guided our research may be helpful. We begin with the assumption that having memorized the building layout, its various rooms, and the location of the objects therein, readers’ mental model of the later story situations will make use of the memory structures representing these entities, along with the goal, location, and movement path of the main character as he or she moves through the story episodes.

The nature of the memory representation for a map (spatial array) is a topic of intense interest and debate among cognitive scientists. On the one hand are proponents of the “perceptual symbol” system such as Barsalou (1999), Glenberg (1997), and Paivio (1990). They propose that the primitive elements of a spatial representation are analog percepts of regions and subre-
regions of space and percepts of the included objects and their locations, so that what is stored from studying a map is rather like an analog, metric "image" of the map. For the present experiment, this analog image would be called into service to represent the situation referenced by the texts. The sentences of the text would then be considered as instructions to run a mental simulation of the characters' actions within this situation model. "Focus" on the character would then be represented as a "spotlight" of intense activation of subregions within the overall image, perhaps by zooming into those regions and enlarging the objects contained therein (see Barsalou, 1999; Kosslyn, 1980). We defer until later commenting on this "perceptual image" representation.

A second representation follows in the footsteps of many others (Anderson & Bower, 1973; Bower & Rinck, 1999; Haenggi, Kintsch, & Gernsbacher, 1995; Hirtle & Jonides, 1985; Kintsch, 1988; McNamara, 1991; McNamara, Hardy, & Hirtle, 1989; Stevens & Coupe, 1978). This view hypothesizes that memory of the building map is represented as a hierarchical structure of the perceptual elements and concepts encoding the map of the building, with links between elements reflecting their geometric relationships. For the present materials memorized by our participants, this hierarchy would encode the rooms of the building in spatial relationships to one another, with connecting doors between some adjacent rooms and with links to the objects contained in each room. Figure 4 sketches a fragment of the kind of hierarchy we use to represent participants' long-term memory of the laboratory building depicted in Figure 1. Symbols in Figure 4 represent perceptual objects (building, rooms, and objects), and links be-

![Diagram of Long-Term Memory](image-url)
between symbols represent labeled spatial relationships (e.g., "contains" or "connecting door") between the nodes. These links can be used to retrieve some idea (symbol) from another idea (symbol) when it is activated by an internal or external cue.

This memory structure is called into service as a participant later reads brief stories describing events occurring in the building. When the person reads (for "deep comprehension") a sentence in the narrative such as "Sandra walked from the library into the storage room," we presume that this sentence is entered into his or her working memory; in turn, the concepts in the proposition transmit activation to the corresponding elements in the memory structure (e.g., the hatched lines going to the room symbols in Figure 4). In addition, we presume that readers spontaneously draw some direct, low-level inferences warranted by the motion sentence, specifically, the protagonist’s path and current location resulting from the character’s motion. In the present case, these inferences would be that "Sandra walked through the laboratory" and "Sandra is now located in the storage room."

These inferences will cause further activation to spread to the symbols representing the actor’s path and present location. It is this inferred, second source of activation that accounts for the distance gradient of priming, that is, greater priming of the current location and some drop-off in priming for the path and source room. This activation on a connected node is presumed to accumulate rapidly once a concept is entered into working memory; it is also presumed to fade away quickly as time passes without that concept being used. This fading of activation with time since a node drops out of focus also contributes to the gradient of priming found as one looks back in time over the character’s path of successive movements. It is this differential activation of propositions and inferences in working memory and their associated symbolic elements in long-term memory that corresponds in this model to what we call the reader’s “focus of attention” within the mental model. It corresponds as well to linguists’ notion of “foregrounding” of elements of a discourse (Chafe, 1979).

As the narrator describes the character moving from room to room in the building, different entities in this long-term memory structure will become activated for awhile but then fade into quiescence as the character or topic of discourse moves on to other things. The activation of a node can be assessed in several ways. One measure used in our earlier work was the time participants needed to answer questions about some entity in the model. The questions were interposed just after motion sentences during participants’ line-by-line reading. Participants might be asked to make a true–false judgment of whether a probe object was in a given room, or they might be asked to decide whether two probe objects were in the same room (e.g., Bower & Morrow, 1990; Morrow et al., 1987, 1989). Asking participants to make these judgments, however, may direct their attention away from reading when it is possible to make the judgments without processing the preceding text. Therefore, additional precautions have to be taken to ensure that participants use spatial knowledge acquired from reading to judge the test probes. Wilson, Rinck, McNamara, Bower, & Morrow (1993) found a spatial gradient of accessibility in probe reaction times only if the test probes included “protagonist probes.” These probes consist of an object and the protagonist’s name, and participants are asked to judge whether the two are currently located in the same room. Obviously, protagonist probes force participants to keep track of the protagonist’s locations and motions.

Concerned that this method placed undue emphasis on participants’ closely tracking locations to answer the interrupting questions, we developed a second, less intrusive measure, namely, the time necessary for participants simply to read an anaphor that referred to some entity in the model (Rinck & Bower, 1995). This method assumes that the greater the priming of the referent symbol in the memory structure, the more quickly the word would be processed, yielding shorter reading times. This anaphor reading time measure proved successful in the earlier experiments as well as in the five experiments reported here. Both assessment methods of priming have led to lawful and converging relationships with a variety of experimental variables.

As noted, the present experiments were motivated by a desire to exploit the “anaphor resolution time reflects retrieval time” metaphor to investigate the effect on reading of variations in the number of objects in the location of the target object (Experiments 1A and 1B), the number of examples of a target object type scattered across different rooms in the building (Experiments 2A and 2B), or all examples of a given type located in the same room (Experiment 3). The findings from the five experiments are sufficiently complex that, as an aid for the reader, we summarize the principal results in Table 6. The entries of Table 6 indicate whether the column variable produced a significant effect in the row variables, which denote the experiment and the word (room, object, or blank wrap-up screen) whose reading time was the dependent measure under consideration.

Table 6 suggests a number of conclusions and generalizations, and we attempt in the following to relate each of them to the hierarchy model described earlier in this section. First, target-room distance from focus has a consistently robust impact on reading

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**Table 6**

**Overview of Effects Observed**

<table>
<thead>
<tr>
<th>Experiment and dependent variable</th>
<th>Target room type</th>
<th>Number of objects</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1A (O-R)</td>
<td>Object name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Room name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Blank screen</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 1B (R-O)</td>
<td>Object name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Room name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Blank screen</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 2A (O-R)</td>
<td>Object name</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Room name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Blank screen</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 2B (R-O)</td>
<td>Object name</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Room name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Blank screen</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 3 (O-R)</td>
<td>Object name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Room name</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Blank screen</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

*Note. O-R = object then room; R-O = room then object.*
time for all three measures: object names, room names, and blank screens assessing wrap-up time for the entire target anaphor sentence. Second, reading time for sentence wrap-up and reading time for room name yield an essentially identical pattern of results, albeit with the room reading times often revealing more robust effect sizes. The one case in which room reading time was in the right direction but did not yield a significant effect (Experiment 2A) was when multiple tokens of the target object were scattered at randomly varying distances from the focus, thus compromising and contaminating the purity of the distance variable.

Third, when object names were unique (Experiments 1A and 1B), the number of objects in a room had no influence on time to read the target object word. This result obtained whether the anaphor referred to “object \(X\) in room \(Y\)” or the reverse order, “in room \(Y\) object \(X\).” The first result would arise in Anderson’s interference model if the “object then room” order gives sufficient head start to the retrieval process begun with the unique object word so that the fan on the room concept (which is presented later) has little opportunity to have any bearing on the outcome. The second null result for the “room then object” order in Experiment 1B is more problematic for Anderson’s fan theory but is consonant with findings of Radvansky and his colleagues (Radvansky & Zacks, 1991; Radvansky et al., 1993), namely, that time to retrieve and verify the location of a unique object is independent of how many objects (over the one to four object range) have been memorized as located there. Radvansky et al. (1993) proposed that such outcomes indicate that all elements situated in a given location model are retrieved together when prompted.

Whether the absence of a fan effect here is a devastating argument against Anderson’s theory depends on side conditions that must be met. It is known, for example, that rapid retrieval of one of a collection of items for a given cue can be mimicked in associative theories by integrating the collection via interitem associations (Anderson & Reder, 1987; Reder & Anderson, 1980; Reder & Ross, 1983; Smith, Adams, & Schorr, 1978). Basically, the retrieval process is facilitated because it can arrive at the desired item either directly or indirectly via chaining through other items associated with the target item. In terms of the associative model in Figure 4, then, the null outcome of a fan of objects in a room might be reflected in a fully interassociated set of nodes encoding the three or five objects in the multi-object rooms.

It is plausible that our participants adopted such integrative strategies for the study and testing conditions of our experiments. Participants studied the whole map at one time in an uncontrolled, self-paced manner, typically concentrating on rehearsing the objects in each room together; similarly, when they recalled the map, they typically output in a cluster of all the objects in one room before moving on to recall the objects in the next room. Conceivably, a fan effect might be induced in this condition if map training and testing conditions were altered to minimize associations among items in the same room. We are doubtful about this possibility, however, because of the results reported by Radvansky and his colleagues (e.g., Radvansky & Zacks, 1991; Radvansky et al., 1993). Their experiments involved learning procedures that should have minimized interitem associations among objects in a given location; nevertheless, they observed no fan effect for multiple objects in a given location.

Returning to Table 6, a fourth finding is that a fully graded fan effect occurred in Experiment 2A in which multiple examples (tokens) of a given object were scattered across one, three, or five rooms. This effect was especially strong in Experiment 2A, because the object name preceded the room name in the target anaphor. In this case, the object name activates one, three, or five possible referents in the different rooms. The uncertainty of which referent is intended causes participants to take longer to read this word. Importantly, in comparison with the unique-object case discussed earlier, there is little chance that our participants would try to integrate the three or five different tokens of the same type that appear in different rooms; if anything, each instance would be clustered together with the other objects in that room. Thus, during anaphor resolution, activation from the object name would be divided among the several links going out to its tokens, dilution of which would slow the time to retrieve one versus three or five tokens of the object type.

The order of object name and room name was reversed in Experiment 2B, and this resulted in a slightly reduced fan effect of 18 ms (vs. 40 ms in Experiment 2A). This reduction was significant in a joint analysis of both experiments, yielding an interaction of experiment and target room type, \(F \left(2, 140\right) = 3.43, \ p < .05\). The reduced fan effect may also be understood in terms of the model. Given the room name first, if it contains only one object, participants can expect that object to be referred to later in the sentence; if the room contains three or five objects, however, then none of the room’s token nodes will receive strong activation. When the object name is read a bit later, the activation from its node will be split among the three or five links to its tokens. The result will be a longer time before the system develops sufficient activation on the referent token node to select it. The fan effect of the number of tokens in this case (Experiment 2B) will be of a “one versus more” variety: Object names with one token will be read faster, whereas those with three or five tokens will be slower and about equal in reading time.

Readers may wonder why the object name reading times in Experiment 2B showed a fan effect at all, because after reading the room name, participants may identify the correct referent for the object name easily: There is only one object in this room, no matter how many others are located in other rooms. So why should there be any interference in this case? Most probably, reading was too fast for this room-name benefit to be fully realized before the object name was fixated. In a different but related study, Radvansky and Zacks (1991, Experiment 3) found that a precue onset asynchrony of 1,000 ms was necessary to reduce interference. Reading times for the noun phrases in Experiment 2B were well below that duration, averaging 364 ms. Nevertheless, some of the expected reduction of interference was observed. Moreover, the expected general facilitation in object-name reading times occurred as well; as a result of the room name acting as a preselection cue, object-name reading times in Experiment 2B were slightly faster than those in Experiment 2A (183 ms vs. 191 ms).

Incidentally, the subtlety of these different effects—of how object tokens affect reading times for room names versus object names in the two orders—brings forth the advantage of using the RSVP method to measure reading time for single words. The level of detail in data collection permits one to examine ever finer details of the predictions of the retrieval theory for anaphor resolution.

The hierarchy theory can also be used to explain the results of Experiment 3, namely, the absence of any influence of number of
object tokens when all tokens of a given type were in the same room but a robust effect of room distance from the current focus. Because the critical anaphors are indefinite expressions (e.g., a chair), the search process in Experiment 3 stops as soon as the first referent node is retrieved. Whether or not the three or five object-referent nodes were integrated during study, under certain assumptions, the time to retrieve the first one of them (given the object name in the text) can be predicted to be the same as when there is only one of them in the room. The result is akin to the expected finishing time for the fastest of \(N\) racers, each with exponentially distributed finishing times, each going at one \(1/N\) the standard rate (see Logan, 1988). The fastest of \(N\) exponential racers has a finishing rate of \(N \times r\). However, if the speed of the individual racers is reduced by the number, as in \(r/N\), then the net effect on finishing time is the same as that for a single racer (i.e., \(N \times r/N = r\)). Because all tokens of a given object type are in the same room, all are activated to a greater or lesser degree depending on the distance of the room from the current focus; thus, retrieval time for any one of them reflects that room-distance-based activation, just as would retrieval time for the room name itself. This was the pattern of results observed.

In conclusion, by varying the number of different objects in a location (room), the number of different examples of an object type in one room or scattered across several rooms, and the order in which the object name and room occur in the target anaphor, we have produced a fairly complex pattern of data regarding the reading time for single target words (object and room names). Surprisingly, this complex pattern of results seems fairly well accommodated in a general way by the type of theory depicted in Figure 4 (e.g., Bower & Morrow, 1990; Bower & Rinck, 1999; Rinck & Bower, 1995). As applied to reading, the model assumes that readers use long-term memory structures that are activated by sentences entered into working memory as they are read, a common assumption in theories of reading comprehension (see Kintsch, 1988, 1998). The model accords special status to these propositions in working memory and their activated counterparts in long-term memory. These activated concepts and perceptual symbols serve to establish the “here and now” point in the flow of the narrative.

Before closing, it is appropriate to consider the hierarchy theory in Figure 4 and its relation to the perceptual image representations of spatial layouts mentioned earlier. Our view is that the hierarchy simply depicts the geometric and proximity relationships among subregions of a spatial layout and the objects and landmarks it contains. For our purposes here, it is the proximity relationships among elements that are important for understanding the spatial priming results, not their exact “content.” The elements in Figure 4 could be interpreted either as abstract, amodal concepts or as perceptual symbols pointing off to long-term memory routines for “running” an image-generation program (Barsalou, 1999; Glenberg, 1997; Kosslyn, 1980). One problem for the perceptual image approach is that of specifying how language contacts the memo- rized perceptual structures and gives rise to the analogical mental simulation (e.g., of the characters’ movements). In addition, results from a number of studies (Hirtle & Jonides, 1985; Langston, Kramer, & Glenberg, 1998; McNamara, 1991; McNamara et al., 1989; Rinck, Hähnel, Bower, & Glowalla, 1997) indicate that spatial situation models lack some aspects of metric analogs of the space. For instance, Rinck et al. (1997) found that spatial distance represented in situation models is categorical rather than Euclidean in nature. Moreover, a distinction might be made between the way spatial distance is represented in the situation model and used for reading and the way it is represented in the map that participants memorized before reading the narratives. It might very well be that the map is represented analogically (e.g., as perceptual images), whereas the situation model used for reading is not nearly so detailed because it integrates spatial information from the map with information derived from the text. These are theoretical issues best left for resolution in other venues.

To summarize, we have conceived of anaphor resolution as partly involving a memory look-up component. Our experiments investigated how anaphor resolution might be influenced by a classic memory variable, namely, interference created by a multiplicity (fan) of uses of a given concept. The results appear to show that the memory perspective is useful for investigating and understanding the impact on comprehension of a variety of memory and psycholinguistic variables.

References

de Vega, M. (1995). Backward updating of mental models during contin-


(Appendix follows)
Sandra and Her Missing Notes

Sandra had just been promoted to research associate at the center. Today she was nervous because she was going to have her first meeting with the director. She went into the conference room to prepare for the meeting. She reached into her briefcase for her notes and discovered to her horror that the notes were missing.

She tried to calm herself and think where they might be. She entered the library, reassured by the thought that the notes had to be in the building because she had brought them with her that morning.

Motion Sentence
She walked from the library into the storage room.

Coherence Sentence
She tried to remember where she had left her notes that morning by mentally retracing her steps.

Anaphoric Target Sentence
Location: She remembered that she had been standing in front of the chair in the storage room earlier that day.
Path: She remembered that she had been standing in front of the computer in the laboratory earlier that day.
Source: She remembered that she had been standing in front of the calendar in the library earlier that day.
However, she was pretty sure that she hadn’t left her notes there. She didn’t think she had left her notes among all the stored junk in the storage room either, but she looked around anyway.
Beginning to panic, she rushed into the repair shop.
She looked all over the repair shop, but she didn’t see the notes.
So she walked from the repair shop into the lounge.

Additional Object Sentence
Three objects: She looked nervously around and checked every possible place behind the television and even in the refrigerator.
Five objects: She looked nervously around and checked every possible place behind the television, under the bed and the coke machine, and even in the refrigerator.
She tried to recall what her notes said since she was quickly losing any hope of finding them.

Motion Sentence
Finally, she walked from the lounge into the office.

Coherence Sentence
She remembered looking over the notes during breakfast, so she tried to remember where that had been.

Anaphoric Target Sentence
Location: She recalled that in the morning, she had eaten something while looking at the phone in the office.
Path: She recalled that in the morning, she had eaten something while looking at the clock in the experiment room.
Source: She recalled that in the morning, she had eaten something while looking at the mirror in the lounge.

Had she left her notes there?
She was overcome by relief when the secretary told her she had found the notes by the telephone.

Sandra still had time to prepare for the meeting, so she grabbed the pages and told the secretary that she would be in the conference room if the director asked.

Question 1: Did Sandra search the conference room for her notes?
Question 2: Did Sandra have her notes with her during breakfast?
Question 3: Did Sandra find the notes herself?

Note: Explanations are given in the text.