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Spatial Coding and Discourse Models During Text Reading

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Text comprehension involves frequent backtracking through previously read material, either accompanied by regressive saccades or not, in order to find the elements necessary for the interpretation of words currently being inspected. An obvious example is anaphor processing, where reference to an earlier element in the text, and thus the necessity to backtrack, is marked linguistically (by a pronoun, a definite article, a preposition, etc.). Little is known, however, concerning the exact nature of the text representation(s) used by readers when performing such backtracking. In the present paper, two potential levels of text representation will be discussed: a representation of the text *content* (see, for example, the notion of a discourse model proposed by Garnham, 1981) and a representation of the surface form of the text, including the *spatial locations* of words on the screen.

INTRODUCTION

The idea that readers retain *some* spatial information is certainly not a new one. For example, it has been shown that after having read a one-page text, subjects are able to indicate in which corner of the page (e.g. upper-left, lower-right, etc.) the answer to a given question is to be looked for (Christie & Just, 1976; Rothkopf, 1971; Zechmeister & McKilipp, 1972; Zechmeister, McKilipp, Pasko, & Bespalec, 1975). More recently, eye movement recording was used to investigate the role of "spatial coding" (Kennedy, 1991) in the visual re-inspection of a line of text. For example, Kennedy and Murray (1987a) asked subjects to check for the presence of a given word in a sentence they had just read. In such a situation, the

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accuracy of regressive saccades does not depend on their span, as though the reader somehow "knows" where the target is on the line. The first aim of the present paper was to extend such findings to multi-line displays: after having read a short text and removed it from the screen, subjects had to point to the *previous location* of target words by using the computer mouse.

The second aim was to investigate the possible functional links between memory for word locations and memory for text content. The fact that readers are able to locate some words on the screen when explicitly asked to do so does not mean that surface level information is necessary for re-accessing discourse model entities. For example, Rothkopf (1971) found a correlation between recall of word location and recall of content. The direction of the observed relation is still open to debate, however. Is the retrieval of word locations a prerequisite to the evocation of text content, or does the content level come first? As far as anaphor processing is concerned, the results reported by Lucas, Tanenhaus and Carlson (1990), Murphy (1985) and Tanenhaus and Carlson (1990) suggest that both the linguistic form of the antecedent and the corresponding abstract entity in the discourse model are involved. Here again, one might ask whether access to the antecedent necessarily *precedes* access to the discourse model and whether it is required for anaphor interpretation. Even in a situation where anaphor interpretation is accompanied by a regressive saccade towards the antecedent (Kennedy & Murray, 1987b; Murray & Kennedy, 1988; Pynte, Kennedy, Murray, & Courrieu, 1988), it is still possible to argue that a discourse model entity was accessed *before* re-inspection of the surface form. In order to address this issue, two versions of each text used in our experiments were prepared, namely an "anaphoric" version and a "non-anaphoric" version depending on the article in the third sentence (e.g. "the" or "an" before "officer" below).

Headquarters today are in an uproar.
A lieutenant from the cavalry fell down in the courtyard.
Claudine quietly questioned *the/an* officer.
Immediately, he responded with a smile.

After reading one of the two versions of a given text, the subject had to point to the previous location of a target word on the screen, by using the computer mouse. In the above example, the target was either "lieutenant" or "officer". In many respects, this procedure is similar to the probe-word recognition paradigm (where subjects must decide whether a given probe-word was present in the text) that has generally been used in the anaphor literature (Chang, 1980; Cloitre & Bever, 1988; Dell, McKoon, & Ratcliff, 1983; Greene, McKoon, & Ratcliff, 1992; Lucas et al., 1990; Murphy, 1985; Tanenhaus & Carlson, 1990). In these studies, it has been shown that

antecedents are better recognised than non-antecedent control words (e.g. "lieutenant" in the definite-article version as compared to the indefinite-article version). This effect has been interpreted in terms of "reactivation" of the antecedent (by the nominal anaphor). It is not clear, however, whether such reactivation concerns the surface form of the antecedent or the corresponding abstract entity. Moreover, little attention has been paid so far to the memory representation of the nominal anaphor itself (e.g. "officer" in the definite-article version as compared to the indefinite-article version). An important feature of the present study is that both the antecedent and the anaphor were used as target words. We would like to claim that, unlike antecedents, anaphors become *less* accessible than non-anaphor control words.

The rationale of this prediction relies on two assumptions, namely: (a) that accessing the surface form of a word (especially when this word is embedded in an anaphoric expression) involves the previous retrieval of the corresponding entity in the discourse model; and (b) that the surface form which *first* introduced an abstract entity in the discourse model is more easily accessed through this abstract entity. Let us assume that these two assumptions are true. Then, one can expect some confusion to occur between the location of "the officer" and the location of its antecedent "lieutenant" (the target word being "officer"). Indeed, after having retrieved the abstract entity corresponding to "officer", the subject would actually have access to the surface form "lieutenant" (since "lieutenant" first introduced the abstract entity corresponding to "officer"). As a consequence, he or she may be tempted to point to the spatial location of "lieutenant" instead of the location of "officer". By contrast, if surface forms are accessed independently of discourse model entities, then pointing performance (in particular when "officer" is the target) should be similar for both the definite- and indefinite-article versions.

EXPERIMENT 1

Method

Subjects. Twenty-five right-handed native French speakers between the ages of 23 and 30 took part in the experiment. They were not paid for their participation.

Linguistic Materials. Twenty experimental texts were generated according to the following scheme. Each text contained four sentences. The first sentence denoted a place or event (e.g. a military headquarters, a strike, a bookstore) where certain individuals or entities were likely to be

found (officers, workers, books). The syntactic subject of the second sentence and the object in the third sentence referred to one of these entities. In addition, there was a subordinate-to-superordinate relationship between them (e.g. lieutenant and officer; ironworker and worker; novel and book). The subordinate noun was always followed by the superordinate noun. Two versions of each text were set up (see above). In the non-anaphoric version, the superordinate (object of the third sentence) was introduced by an indefinite article (e.g. an officer, a worker, a book). In the anaphoric version, it was introduced by a definite article (the officer, the worker, the book). The subject of the last sentence was always the French pronoun "il" (he/it).

Experimental Device. The subjects were seated in front of a high-resolution MCGA graphic screen driven by an IBM PS/2 microcomputer equipped with a mouse. They used the mouse's right button to display the texts, sentence by sentence, following the self-paced procedure. At the beginning of each trial, the screen was empty. Each sentence took up one screen line. Once read, the sentences (lines) were replaced by a series of ×'s with spaces between words. Pressing on the right button of the mouse after the last sentence was read caused the screen to be cleared and a rectangle to appear at the bottom. The subject then clicked on the rectangle with the left button of the mouse to display the target word. As soon as the target word appeared, the subjct was required to point with the mouse to its prevous location in the text. The pointing was terminated by another clicking of the left button of the mouse. The spatial layout of the words on the screen is shown in Fig. 1. The average angle formed by the subordinate noun ("lieutenant") and the horizontal line passing through the rectangle containing the target word was 120°. That angle was 62° for the superordinate noun ("officer").

Procedure. After three practice texts, the subjects processed 20 experimental texts mixed with 10 filler texts. Half of the experimental texts were presented in their anaphoric version (definite article), and half in their non-anaphoric version (indefinite article). Two lists of texts, associated with two groups of subjects, were set up in order to balance versions across texts. Each subject was asked to point twice. The first time pertained to a single word in the text, either the subordinate noun (e.g. "lieutenant") or the superordinate noun (e.g. "officer"). The second pertained to a target made up of a pronoun (subject or object) and a verb. The subject's task was to point to the antecedent of the pronoun in the text. Two examples of targets are "*He* fell down", which refers to "A lieutenant fell down" in the text, and "She questioned *him*", which refers to "Claudine questioned an/the officer" in the text. The critical pronoun was boxed to make it stand out

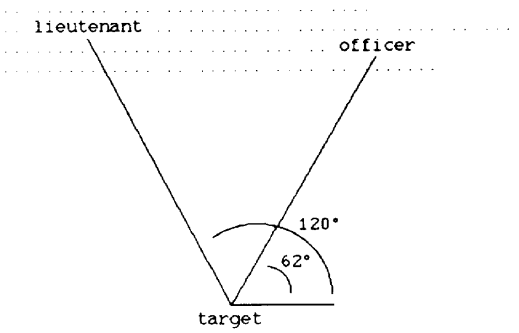

FIG. 1 Spatial layout of the words on the screen. Non-target words have been replaced by dots here but were not in the experiment. The subjects saw one line at a time and had to clear the screen before making the target appear.

from the other words in the target. The targets for filler texts were located anywhere.

Results and Discussion

All the analyses were conducted following a 2 (type of article) × 2 (type of target) × 2 (item list) design. Type of article and type of target were both within-subject factors; item list was a between-subject factor.

Pointing Direction. For each trial, a line was drawn between the point that the subject indicated on the screen and the middle of the rectangle containing the target at the bottom of the screen (starting point). The dependent variable was the angle between this line and the horizontal line passing through the starting point. The results are given in Table 1. The subjects moved correctly towards the subordinate ("lieutenant") when it

TABLE 1
Pointing Direction (in Degrees from the Horizontal) by Experimental Condition

	No Co-referential Link (a lieut . . . an officer)		*Co-referential Link (a lieut . . . the officer)*	
Target	*Lieutenant*	*Officer*	*Lieutenant*	*Officer*
First pointing (noun)	121	90	122	89
Second pointing (pronoun + verb)	123	82	123	97

was the target. They pointed approximately vertically, i.e. in a direction somewhere between the subordinate and the superordinate, when the superordinate ("officer") was the target. This result seems to be linked to a confusion between the subordinate and the superordinate rather than to a lack of pointing accuracy. Indeed, the distribution of pointing directions was clearly bimodal. Very few responses were actually vertical. Approximately half were located around the subordinate and half around the superordinate.

As far as the first pointing is concerned, confusions between the two nouns was similar for both types of article. In particular, when the target was the superordinate ("officer"), no difference in direction was observed between the indefinite and definite article versions (89° *vs* 90°). An analysis of variance conducted for the first-pointing data yielded no significant interaction between type of target and type of article ($F < 1$), although a significant main effect of type of target [$F(1,24) = 32.536$, $P < 0.001$] was found. This merely means that the overall pointing direction was different for the two types of targets.

As for the second pointing, both the main effect of type of target, and the interaction between type of target and type of article, were significant [$F(1,24) = 16.55$, $P < 0.001$; $F(1,24) = 5.579$, $P < 0.05$, respectively], which suggests that readers were able to spatially locate the antecedent of a pronominal anaphor. Remember that during the second pointing, the word to be pointed to was not given in the expression describing the target, which was a pronoun ("he" or "him") associated with a verb. This task thus involved identifying the antecedent of the pronoun before pointing to the position it occupied in the text.

Consider the case where the target verb presented was associated with the superordinate noun in the text (example of a target: "She questioned him", referring to the sentence in the text "Claudine questioned the/an officer"). In this case, a significant difference in pointing direction was observed according to whether the word "officer" was preceded by a definite (97°) or an indefinite (82°) article. This 15° difference was found to be significant in the analysis of variance [$F(1,24) = 13.825$, $P < 0.01$]. It looks as though subjects in this condition tended to point to that pronoun antecedent which was located higher up in the text, e.g. to "officer" when there was an indefinite article, but to "lieutenant" when there was a definite article.

Now, consider the case when the verb in the probe expression was associated with a subordinate noun in the text (example of a target: "He fell down", referring to the sentence "A cavalry lieutenant fell down" in the text). There is no reason for the type of article to have an effect. The antecedent of the pronoun was "lieutenant", regardless of what article

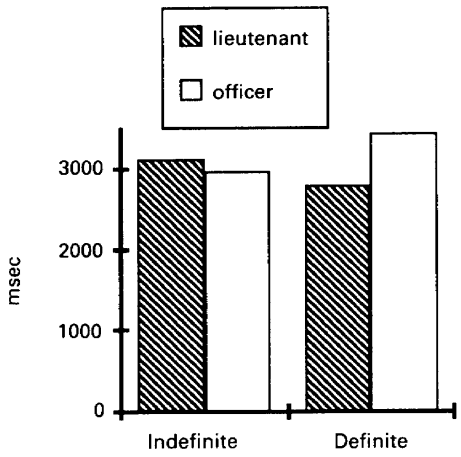

FIG. 2 Total pointing time (msec) for the two targets (lieutenant *vs* officer) as a function of text version (indefinite *vs* definite article).

came in front of "officer". As predicted, no difference was observed between "the officer" and "an officer" (123° for both types of articles).

Temporal Indexes. No significant effect was found for the second pointing (all F's < 1). Only the results for the first pointing will be discussed below. Total pointing time (between when the subject clicked to display the target and when he or she clicked to end the pointing) is shown in Fig. 2. The analysis of variance on this data yielded an interaction between type of target and type of article [$F(1,24) = 5.65$, $P < 0.05$]. The longest pointing times were recorded when "officer" was the target and when it was linked to an antecedent located higher up in the text (definite-article version). Pointing times for "officer" were longer than pointing times for "lieutenant" in this case [3435 *vs* 2793 msec: $F(1,24) = 8.06$, $P < 0.01$].

A possible account would be to consider that determining the screen location of a nominal anaphor first involves retrieving the corresponding entity in the discourse model. Only afterwards would subjects attempt to locate the position of the word associated with the selected entity. In this line of reasoning, the observed difference between "lieutenant" and "officer" in the definite-article condition suggests that the screen location of antecedents is more directly accessible. This does not mean, however, that the previous retrieval of the corresponding abstract entity is not necessary in this case as well. Another interpretation is possible, namely that entities in the discourse model remain specifically tied to the linguistic expression used to introduce them in the discourse model. Later co-

TABLE 2
Time Measures (msec) for the First Pointing by Experimental Condition

	*No Co-referential Link (a lieut . . . **an** officer)*		*Co-referential Link (a lieut . . . **the** officer)*	
Target	*Lieutenant*	*Officer*	*Lieutenant*	*Officer*
Reaction time	1222	1069	960	1044
Movement time	508	521	520	575
Stopping time	1378	1385	1312	1816

referents (and/or their locations) would in this case also remain available, but only afterwards. Take the example of "officer" as the target word. The location of "officer" would be searched for after detection of a mismatch between the target word and the screen location of "lieutenant". Since the entity corresponding to "officer" was introduced during the reading of "lieutenant", the word "lieutenant" would be accessed first.

In order to further examine this issue, total pointing time was broken down into three components, namely:

1. *Reaction time*: the time between the appearance of the target word and the beginning of movement (see first row in Table 2).
2. *Movement time*: the time during which the mouse was moving (second row in Table 2).
3. *Stopping time*: the sum of all the pauses during movement (third row in Table 2).

Reaction time was *shorter* in the definite-article condition than in the indefinite-article condition [$F(1,24) = 6.867$, $P < 0.025$]. Of particular interest here is the difference observed when "lieutenant" was the target [1222 *vs* 960 msec: $F(1,24) = 7.22$, $P < 0.025$]. The presence of a definite article in front of "officer" apparently facilitated the retrieval of "lieutenant". This is in keeping with previous results suggesting that anaphors reactivate their antecedents (Chang, 1980; Cloitre & Bever, 1988; Dell et al., 1983; Greene et el., 1992; Lucas et al., 1990; Murphy, 1985; Tanenhaus & Carlson, 1990). The fact that this effect was observed on reaction time here, and not on movement time or stopping time, suggests that such reactivation does not concern surface level information. Actually locating the word "lieutenant" on the screen was *not* easier in the definite-article version. Instead, a *lengthening* of movement time was observed in this case, for both "lieutenant" and "officer" [$F(1,24) = 4.662$, $P < 0.05$, for the main effect of type-of-article on movement time]. The reactivation

of "lieutenant" (probably at the content level, see above) apparently led to confusions between "lieutenant" and "officer" at the surface level. This latter effect can be explained if it is assumed that in the definite-article condition, a single abstract entity was linked to two distinct words. By contrast, whenever there was no co-referential link (indefinite-article condition), there was a one-to-one correspondence between the entities in the discourse model and the target words, such that the act of locating could be performed without ambiguity. The observed interaction between type of target and type of article for total pointing time (see Fig. 2) only reached significance for stopping time during pointing [third row in Table 2: $F(1,24) = 5.135$, $P < 0.05$]. The longest stopping times (suggesting hesitations) were observed for "officer" preceded by a definite article in the text. Again, this is consistent with the hypothesis according to which antecedents (e.g. "lieutenant") are more directly associated with abstract entities than anaphors are (e.g. "officer").

EXPERIMENT 2

Despite the difficulties discussed above, the subjects eventually succeeded in locating target words, in particular for antecedents. This result is in keeping with the spatial coding hypothesis: Readers are able to retrieve the spatial location of some words when explicitly asked to do so. However, the spatial coding hypothesis has been questioned on the grounds that a *temporal* encoding of the order in which words were encountered in the text would provide basically the same information, and would thus account for regression control (Monk, 1985) as well as for the pointing data presented here. In order to combat this objection, two versions of the self-paced procedure were compared in Experiment 2, namely a "spatial" mode of presentation (preserving the normal position of words) and a "non-spatial" mode (all words appearing at the same location). Obviously, the use of a pointing procedure was not possible for the non-spatial mode of presentation. A variant of the probe-word recognition paradigm was used instead for both conditions. After having read a text (the same texts as in Experiment 1), subjects were asked to decide whether a given expression had been used. The subjects were instructed to check for the exact wording of the expression, and not to rely only on its meaning. If it is true that in normal reading spatial locations are stored along with words, and if knowing spatial locations can help the subject remember surface forms, then fewer errors (e.g. confusions between surface forms) can be expected in the spatial mode. It should be noted that the two modes of presentation were comparable as far as *temporal* cues are concerned. In particular, the order in which words were encountered was the same. Any

observed difference should thus be attributed to the presence of extra *spatial* cues in the spatial mode.

Method

Subjects. Forty native French speakers between the ages of 23 and 30 served as subjects in the experiment. They were not paid for their participation.

Linguistic Materials. The experimental texts were identical to those used in Experiment 1. Twenty filler texts were added instead of ten.

Apparatus and Presentation Modes. The subjects were seated in front of a high-resolution MCGA graphic screen driven by an IBM PS/2 microcomputer. The space bar on the keyboard was used to display successive segments of text (self-paced paradigm). Two keys adjacent to the space bar, marked "yes" and "no", were to be used for responding. The sentences were segmented syntactically into four parts, e.g. "A lieutenant/ from the cavalry/fell down/in the courtyard". Two presentation modes were compared: in the non-spatial mode, segments were always displayed in the same place in the middle of the screen; in the spatial mode, each word occupied a specific location on the screen. This location was the one it would have occupied had the entire text been presented at once. Each word location was indicated in advance by a series of ×'s. When a given segment was displayed, it replaced the corresponding series of ×'s on the screen. These ×'s reappeared with the next segment.

Experimental Design and Procedure. After three practice texts, the subjects processed 20 experimental texts mixed with 20 filler texts. Half of the experimental texts were presented in the anaphoric version (definite article), and half in the non-anaphoric version (indefinite article). Two lists of items associated with two groups of subjects were set up in order to balance versions across texts. Each text was read twice. After the second reading (the text was no longer on the screen at this point), a probe appeared on the screen. This probe was an expression consisting of the superordinate noun and the verb associated with the subordinate noun in the text. The expression was followed by suspension points. In the preceding example, the probe was "the officer fell down . . .". The subject was to state (by pressing the "yes" or "no" key) whether or not that probe had been in the text. The correct response was always "no" (the sequence "the officer fell down" was *not* in the text). The probes for the filler texts were chosen in such a way that there was an equal number of "yes" and "no" answers in the experiment.

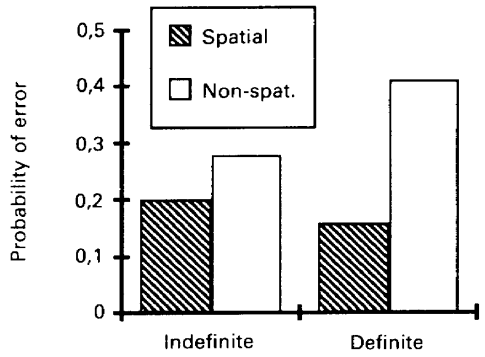

FIG. 3 Error rate in the four conditions of the experiment (spatial *vs* non-spatial mode; indefinite-article *vs* definite-article version).

Results and Discussion

The analysis was of a 2 (type of article) × 2 (presentation mode) × 2 (item list) design. Type of article was a within-subject factor, whereas presentation mode and item list were between-subject factors. Responding was faster [3148 *vs* 3949 msec: $F_1(1,32) = 5.846$, $P < 0.025$; $F_2(1,16) = 36.276$, $P < 0.001$] and fewer errors were made [0.18 *vs* 0.35: $F_1(1,32) = 0.09$, $P < 0.01$; $F_2(1,16) = 22.78$, $P < 0.001$] in the spatial mode.

There was also an interaction (on error rate only, see Fig. 3) between presentation mode and type of article [$F_1(1,32) = 8.45$, $P < 0.01$; $F_2(1,16) = 12.68$, $P > 0.01$]. In the presence of a co-referential link between the superordinate and subordinate nouns, subjects who had read the texts in the *non-spatial mode* tended to confuse "officer" and "lieutenant" more often [simple effect of the type of article factor for the non-spatial mode: $F_1(1,32) = 9.88$, $P < 0.01$; $F_2(1,16) = 14.82$, $P < 0.01$]. In the *spatial mode*, such a co-referential link did not lead to confusion of the words actually present in the text (both F_1 and $F_2 < 1$). This is compatible with the idea that the representation that is generated in the spatial mode includes a spatial index for linguistic forms, thus allowing for later retrieval of those forms despite any existing co-referential links.

CONCLUSIONS

A first aim of this paper was to confirm that readers retain the spatial location of the words read. Pointing performance in Experiment 1, especially for the second pointing, was consistent with this hypothesis: The subjects were apparently able to retrieve the spatial location of pronoun

antecedents with a reasonably good level of accuracy. It is important to note that pointing was actually performed on an empty screen (the text having been removed). This suggests that the role of spatial information is not restricted to controlling regressive saccades. Most probably, a search through a *memory representation* of the text was involved here, although it cannot be excluded that some sort of reading-like re-inspection was performed in the absence of actual text. The results of Experiment 2 also support the spatial coding hypothesis. The spatial mode (which promotes a memory representation including the screen location of words) apparently prevented confusion between co-referents: in the spatial mode, errors were not more numerous for the definite-article version than for the indefinite-article version. We interpret this finding as an indication that access to surface forms in a text can benefit from the retrieval of the corresponding locations on the screen. Since the temporal orders of both the spatial and non-spatial modes were equivalent, an account in terms of a temporal code (Monk, 1985) is not possible here.

Another interesting aspect of the results of Experiment 1 is the interaction found between type of article and type of target for pointing times. Pointing towards a word location took more time when this word was part of an anaphoric expression, i.e. when it was preceded by a definite article as opposed to an indefinite article. This suggests that re-accessing previously read words in a text might involve retrieving the corresponding referent in a representation of the text's content. A two-step account of the pointing results was proposed, the first step consisting of finding the entity to which the target refers, and the second of finding the screen location of the corresponding surface form. Whatever the precise mechanism responsible for this interaction, it is clear that the discourse model level is involved in some way. A slightly different (and more radical) interpretation would be that spatial coding directly indexes abstract entities (instead of surface forms). When two words are co-referent, that is, when they refer to a single entiy, only one screen location would be stored, namely the one where the entity was first introduced in the discourse model. Apart from this assumption, the lengthening of pointing times for words embedded in anaphoric expressions could be explained in much the same way. This new interpretation is consistent with Kennedy's (1991) recent proposal that readers might remember the point in space where such and such a "*cognitive operation took place*" rather than the location of words.

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