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Abstract

The aim of this study was to investigate the construction of a retrieval structure during reading, according to the hypothesis that text macrostructure is used in Long-term working memory (Ericsson & Kintsch, 1995) to maintain encoded information in an accessible format. We first designed an experiment for testing the hypothesis that retrieval structure is a macrostructure of the text. Then, we conceived and run a model inspired by CI-LSA Framework (Kintsch, Patel & Ericsson, 1999) in which a generalization process create macropropositions. Results are that simulation data were found to be highly correlated with participants' data.

Macrostructure as Retrieval structure

Classical view of working memory assumes that during reading relevant information is stored in a Short Term Memory Buffer (STMB; Baddeley, 2000; Kintsch, 1988). In contrast, Ericsson & Kintsch (1995) argued that during reading, readers could encode information in an accessible format in a retrieval structure in long-term working memory (LTWM) consisting of retrieval cues associated with encoded information in Long Term Memory (LTM). Ericsson and Kintsch (1995) showed that clearing STMB by using a reading interruption procedure (Glanzer, Fisher & Dorfman, 1984) does not lead to comprehension impairment. We have also shown that the more a text is familiar, the more readers can construct an efficient LTM retrieval structure based on the content of the text (Bellissens & Denhière, 1998; Denhière & Bellissens, 1999).

A CI-LSA Framework has been proposed (Kintsch, 1998 ; Kintsch, Patel & Ericsson, 1999) to explain LT-WM intervention in the comprehension process. The main characteristic of this framework is the combination of a model of semantic memory, LSA (Landauer & Dumais, 1997), and of a model of comprehension, CI (Kintsch, 1988).

LSA represents potential signification of words belonging to a textual corpus in a semantic space. In the semantic space, vectors represent the words and the cosine of the contained angle of two vectors is an estimation of their respective words similarity. The more the cosine is close to 1, the more the two words are considered as semantically similar. The cosine similarity can be used to weight links in an associative network in which each node is a word. In CI, the use of associative network is the way to represent activated knowledge associated with concepts and propositions derived from text processing. Hence, architecture of a text segment representation in CI-LSA is a network that comprehends propositions and concepts (nodes) linked with each other by relations (links) weighted by LSA cosine. This CI-LSA combination improves the previous comprehension model proposed by Kintsch (1988) by the fact that LSA can model knowledge base in CI.

While Ericsson and Kintsch (1995) assumed that the episodic structure of a text could be a retrieval structure, Kintsch, Patel and Ericsson (1999) did not explain exactly how the CI-LSA framework simulates the construction of a retrieval structure. We assume that each text segment processing results in an individual episodic trace. We propose that the set of episodic traces generated by the text processing is replaced by a macrostructure, resulting from the application of a generalization process (O'Reilly & Rudy, 2000). This generalization process generates macropropositions that are associated with the encoded information for further use as semantic retrieval cues. We argue that if two relevant segments of a text, associated with such retrieval cues, are given after a reading interruption, readers should easily reinstate these retrieval cues and counteract the interruption effect. For example, imagine an individual reads a text about the invention of a machine. He/she reads that the machine has a particular function. Then, the text says that the machine includes one component with a specific function, then a second component with an other specific function. At this moment, the reading is interrupted and then resumed after the presentation of a probe sentence. After Ericsson and Kintsch (1995) and Bellissens and Denhière (2003), the probe sentence should help reader for reinstated semantic cues in STM associated with information encoded in LTM when the previous text has been processed.

The present paper tries to explain how this reinstatement usually occurs and how the reinstatement depends on the organization of the retrieval structure. As we assume that the construction of the retrieval structure is a generalization process, we predict that a sentence mentioning the two components of the machine is a better probe sentence than a sentence comprising two distinct facts: the machine function and the function of a machine component; Indeed, the first type of probe sentence relies on a particular part of the retrieval structure of the text, a macroproposition: machine usually possesses components. The second relies on two separated parts of the macrostructure: the functions of the machine and its component.

What we have just described is a formal view of the conditions we constructed for the following experiment. We predict that if a categorical probe sentence (CAT) is inserted after a reading interruption, readers should resume the reading faster than with a functional probe sentence (FUN).

Table 1: Texts facts

Nb	Sentence
Title	The /Machine/
1	The /Machine/ was invented in /Date/ by /Inventor/
2	The /Machine/ possesses a /Component 1/ to /Component 1 Function /.
3	The /Machine/ is mainly used to /Main Function of the Machine/.
4	The /Machine/ possesses a /Component 2/ to /Component 2 Function /.
5	This component thus contributes to the function of the /Machine/.
6	Since its invention, the /Machine/ is an equipment that was modernized.
7	The modernization of the /Machine/ was useful for the development of /Human Domain/.
CAT	The /Machine/ possesses a /Component 1/ and a /component 2/ to /Component 2 Function /.
FUN	The /Machine/ is used to /Main Function of the Machine/ and possesses a /Component 2/ to /Component 2 Function /.
ORI	The /Machine/ possesses a /Component 2/ to /Component 2 Function/.

Experiment

Participants

Participants were 64 students from Université de Provence, Aix-en-Provence, France.

Materials and Procedure

Twelve pairs of experimental texts and eight pairs of filler texts were generated. A text pair consisted of a main text, an interrupting text, and five comprehension questions. The main experimental texts and the main filler texts described a machine (e.g., the automobile, the elevator, the phonograph, etc.). The main experimental texts all had the same structure (see, Table 1) but the main filler texts did not. The interrupting texts were stories totally unrelated to the main texts.

An experimental trial included the presentation of the main text, the interrupting text, and five text comprehension questions. It began with the self-paced display of the main text, sentence by sentence. An experimental trial included the presentation of a main text, an interrupting text, and five text comprehension questions. It began with the self-paced display of the main text, sentence by sentence. To go on to the next sentence, the reader had to press the space bar on the keyboard. Sentence 2 of the main texts mentioned a machine component and its particular function. Sentence 3 stated the general function of the machine. Sentence 4 gave a second machine component and its particular function. Then a message saying "Attention! Reading time is limited" ("Attention ! Lecture en temps fixé") appeared on the screen. This message stayed on the screen for 1500 ms and meant that the interrupting text would start on the next page. The interrupting text was displayed sentence by sentence for a fixed amount of time (4500 ms per sentence). After the presentation of the interrupting text, a message saying "Attention! Reading time no longer limited" ("Attention ! Lecture en temps libre") appeared on the screen.

Then, one of 4 Probe sentences was displayed: either (i) the original Probe Sentence that was the sentence 4 of the main text (ORI), or (ii) categorical Probe Sentence that contained the two machine components and the second component specific function (CAT), or (iii) a functional Probe Sentence that contained the general machine function, the second component and its specific function (FUN); or (iv) a without Relation Sentence that was a new sentence (WRE). Following the display of the probe sentence, a critical sentence 5 was then displayed. Sentence 5 contained an anaphoric device; the referent was the machine component mentioned in sentence 4 (see, table 2).

In each list, 50% of the main texts were interrupted: Filler texts were never interrupted.

At the end of reading, participants were asked to answer 4 comprehension questions about the main text and 2 comprehension questions about the interrupting text. Second question was the critical question for assessing understanding because its correct answer depends on the encoding of the correct antecedent to anaphora in the fifth sentence.

In the control condition, the first part of the main texts was not displayed; and in the experimental condition, all materials were presented.

Results

Control condition. In the control condition, the first part of the text was not presented. Results are that the critical sentence was read faster in the cued conditions than in the without relation condition, 4221 ms vs. 4597 ms, $F(1,31) = 3,6$ $p<.05$. The critical sentence was read at a same rate in the ORI, CAT and FUN conditions. Note that the sixth sentence was read faster in the probe sentence conditions than in the WRE condition, 3488 ms vs. 3823 ms, $F(1,31) = 4,86$ $p<.05$. Percentage of correct answers to the critical question was greater in the FUN condition than in the CAT condition, 85% vs. 55%, $F(1,31) = 6,49$ $p<.05$ and was greater in the probe sentence conditions than in the WRE condition, 76% vs 42 %, $F(1,35) = 7,8$ $p<.01$.

Table 2: example of text (translated from French)

Nb	Sentence
Title	The elevator
1	The elevator was invented in 1859 by the American Otis.
2	The elevator possesses a sliding door to protect the users from the outside.
3	The elevator is mainly used to reach the floors of a building.
4	The elevator comprises a solid winch that controls the rise of the cabin.
5	This component thus contributes to the utility of the elevator.
6	Since its invention, the elevator is equipment that was modernized.
7	The modernization of the elevator was useful for the development of the residences.
CAT	The elevator possesses a sliding door and a solid winch that controls the rise of the cabin.
FUN	The elevator is used to reach the floors of a building and comprises a solid winch that controls the rise of the cabin.
ORI	The elevator comprises a solid winch that controls the rise of the cabin.

Experimental condition. The critical sentence was read faster in the CAT condition than in the FUN condition, 3869 ms vs. 4437 ms, $F(1,31) = 9.33$ $p<.01$.

The percentage of correct answers to the critical question was greater in the probe sentence condition than in the WRE condition, 55.6% vs. 36.0%, $F(1,31) = 3.9$ $p<.05$., but there was no difference between the CAT and the FUN conditions.

Simulation with CI-LSA+Generalisation Framework

Procedure

Construction Phase. We assumed that a text segment could be represented as an associative network consisting in an explicit and an implicit representation. Explicit representation is the result of a predication analysis of the segment. Implicit representation contained the assumed activated knowledge associated with the concepts and the propositions embedded in the text segments. In the model, the implicit representation was made of all of the nearest neighbors (n=2), taken in an LSA space (General reading up to 1st year college), of each of the concepts and propositions represented in the explicit network. Explicit network was weighted by using the rules provided by Kintsch (1988): link weights between propositions and argument, embedded propositions, and proposition that shared an argument were equal to 1 while others were equal to zero. Implicit network was weighted by using cosine similarity from LSA space. If between two vectors, expressing elements of the net, cosine was .20, the weight of their link in the network was .20.

Integration Phase. This phase is described in Kintsch (1988). Here, the integration phase simulated activation spreading in the net. When the network was settled, the more connected information got the greatest final activation value and for that reason remained in a short-term memory buffer, for the next sentence processing.

Short term working memory. Short-term working memory was involved in the construction and integration phases and in the accessibility of the most activated information. Short-term memory in the model is a temporary memory buffer. It contained the most activated information at the end of a processing cycle. We transformed all final activation values in z-notes. Let a be the average of the activation values, e the standard deviation of the distribution v_i the final activation value of a node I, the z-note of I is:

$$z_i = (v_i - a)/e.$$

Only the nodes with z-notes above a given constant were kept in the Short-Term Memory buffer. Hence, the number of elements in the buffer varied as a function of a limited amount of activation and of the network weighting.

In order to simulate a reading interruption as in the experiment, we emptied the memory buffer: We did not keep any nodes of the last processed sentence.

Long-term working memory. Long-term working memory was a retrieval structure consisting in encoded information and macropropositions associated with it. To simulate the construction of a retrieval structure, we build up a matrix containing in row, all activated information during the different processing cycles and, in column, the different processing cycles. Each cell of the matrix contained the final activation value of an element in a given cycle. If the element was not activated in the given cycle, the cell contained a zero. Hence, this matrix contained all episodic memory vectors. To this matrix was applied a singular value decomposition to simulate a generalization process. The decomposition resulted in three matrices (see, Landauer & Dumais, 1997) but we use the matrix representing the coordinates of each element in a memory space. The elements belonging to that space were projected in a two-dimensional space by reducing its dimensionality. The procedure resulted in a two-column matrix. The macrostructure matrix was the product of the two-column matrix and its transposed matrix. The macrostructure matrix was considered as a generalization of the episodic memory traces encoded from the text.

Table 3 : reading times (RT) and activation forces (AF) of the critical sentence and the probe sentence in Original (ORI), categorical (CAT) and functional (FUN) conditions.

	Critical sentence			Probe sentence		
	ORI	CAT	FUN	ORI	CAT	FUN
RT	14,29	13,16	15,09	8,96	6,94	6,04
AF	11,36	13,76	11,07	11,80	16,66	17,87

Macropropositions reinstatement and reading resumption. After a reading interruption, we assume that readers might be able to readily retrieve mental representation of the text from long-term working memory by reinstating cues associated with encoded information. In the model, macropropositions were reinstated in the short-term memory buffer and were used as context to process the next sentence. As in the experiment above, we used three kind of probe sentences. In a first step, we constructed for each, an episodic trace. As they resume some parts of the previous text, their representation shared information with previous sentences that now belonged to the macrostructure matrix. But the shared information was not as such important for each probe sentence. In the categorical condition, information given by the probe sentence referred to a categorical macroproposition "machine has component", while in the functional condition, the probe sentence referred to "machine has a function" and "component has a function". In a second step, we multiplied the episodic vector trace of the probe sentence by the macrostructure matrix. The result of the product was an echo vector. We z-transformed the coordinates of the echo vector and only kept the z-notes above 1.5. The respective nodes were taken to make part of the critical sentence network. In a final step, activation spread in the critical sentence net.

For each probe sentence, and for the critical sentence, in each condition, we calculated an activation force. The final activation values of each sentence were z-transformed and we summed all the z-values above 0.

Results

We applied this procedure to three experimental texts. For each sentence, the mean activation force and the mean reading times per character and proposition are presented in the table 3. First, for each text, and in each of the probe conditions, the anaphora antecedent was retrieved from the macroproposition structure. Second, the activation force obtained by the model can predict the reading times obtained by participants. The correlation between reading times and activation forces were negative and significantly different to zero, $r=-.83$, $z(6)=-2.0$, $p < .05$.

Discussion

As predicted, the CAT sentence led to a faster critical sentence reading time than does the FUN sentence. This difference is not due to the fact that the CAT sentence contained two potential antecedents for the anaphora in critical sentence. First, the difference appeared only when the first part of the main text was presented. Second, although in control condition, the percentage of correct answers was greater in the FUN condition than in the CAT condition, this difference was not found in the experimental condition. This result indicates that without the first part of the text, readers did not discriminate the right antecedent from the categorical cue sentence. Moreover, in control condition, the presentation of the WRE sentence exerted an effect on the critical sentence 5 and on the sentence 6 reading times. This indicated that, in the control condition, subject could not rely on a retrieval structure built in LTM to counteract irrelevant information effect on text processing. It results that when the readers have the opportunity to construct a retrieval structure, a categorization of two pieces of information (the two machine components) had occurred during text processing, based on meaning overlap between the two learning episodes: sentence 2 and sentence 4.

The CI-LSA+generalisation framework could explain how a retrieval structure was build up: During reading, each sentence of the text was processed and stored in episodic memory. Then, as a function of meaning overlap between them, sentences representations were associated to the same semantic macroproposition in

LTM or were not associated. The remaining question is when does generalization process occur during reading? Does it occur during the encoding process or during the retrieval process ? Research has to answer these question in the future. Nevertheless, generalization process and more generally integration process appear to be necessary processes for building the retrieval structure that permits texts comprehension.

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