TEXT COMPREHENSION IN RESIDUAL APHASIA AFTER BASIC-LEVEL LINGUISTIC RECOVERY: A MULTIPLE CASE STUDY

Running Head: Text comprehension in residual aphasia

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Abstract

Background: Text comprehension entails a complex interaction between cognitive and linguistic factors. In aging, text comprehension depends on text characteristics, particularly semantic load. Persons with residual aphasia may complain of discourse comprehension difficulties without linguistic problems. Three levels of representation are involved in text comprehension (surface level, semantic level constituted by macrostructure and microstructure, and situational level). Attention, verbal working memory, long-term memory, and executive functions combine to allow processing of all levels of representation.

Aims: The primary objectives of this multiple case study were (a) to examine microstructure, macrostructure and situational model updating in text comprehension in five participants with left-brain-damage (PWLBD), who continued to complain about problems with discourse comprehension without linguistic problems, and (b) to examine executive function and memory in these participants.

Methods and procedure: Five PWLBD were selected for the study. We asked the participants to read and understand three narrative texts. The texts varied according to semantic load (the amount of information). In each text, we assessed macrostructure, microstructure and situational model updating. To evaluate memory and executive functions, we administered specific complementary tasks. Results were compared to normative data obtained from a previous study with a total of 60 neurologically intact control participants, divided into younger (N = 30) and older (N = 30) groups.

Outcomes and results: The results for the five PWLBD indicated that text comprehension is influenced by text characteristics, particularly semantic load; the findings demonstrated short-term memory and cognitive flexibility deficits.

Conclusions: These findings have two major implications. Analysing text comprehension using several texts with varying semantic loads is a promising tool for diagnosing residual aphasia and for designing specific cognitive interventions that target reading comprehension abilities in persons with residual aphasia.

Keywords: Text comprehension, Cognitive model of text comprehension, Aphasia, Memory, Executive function

Text comprehension contributes to personal autonomy and quality of life. After recovery from aphasia, individuals who suffer brain damage may complain of difficulties comprehending text, despite normal functioning at the more basic linguistic level. These persons still demonstrate residual aphasia, being on the border between mild aphasia and normality (Jaecks, 2012). Unfortunately, their problems cannot be identified by clinical assessment. Aphasia batteries are unable to diagnose their text comprehension deficits. The situation challenges both the patient and the speech-language pathologist. The therapist is unable to plan treatment without clearly identifying the patient's difficulties and demonstrating the necessity of continued therapy (both for the patient and for insurance coverage). Few studies have evaluated the diagnostic possibilities of residual aphasia (Jaecks, 2012; Ross, 2004) and to our knowledge, no study has examined text comprehension in the case of residual aphasia.

In clinical aphasiology, comprehension assessment usually tests the phonological, morphological, syntactic, and semantic aspects of language. However, to describe and assess text comprehension of persons with brain damage, one must consider the various linguistic and cognitive dimensions that interact during text processing. This consideration is particularly important when the patient complains of text comprehension difficulties but does not present any deficit at the basic linguistic level.

Text comprehension

Text comprehension entails a complex interaction between linguistic and cognitive factors. Higher-order cognitive processes such as attention (Hula & McNeil, 2008), verbal working memory (Liu, Kemper, & Bovaird, 2009), long-term memory (Was, 2007), and executive functions (R. C. Martin & Allen, 2008) are as important as linguistic skills for text comprehension.

Current models of text comprehension suggest that understanding involves several levels of representation (Cook, 1998; Kintsch, 1988; Rizzella & O'Brien, 2002; Van Dijk & Kintsch, 1983). The first level corresponds to the surface level or the linguistic form of the text. The second level corresponds to the semantic content of the text, consisting of the microstructure (details) and the macrostructure (main ideas) of the text. The number of micropropositions provides the semantic load of the text. The third level corresponds to the situation inferred by the reader from the text information and his knowledge of the world: it is the situation model or the mental model (Johnson-Laird, 1983).

In this study, we have chosen to refer specifically to the Kintsch model because it accounts for the different levels of representation in text comprehension and cognitive functions that allow the transition from one level to another (Kintsch, 1988). According to the Kintsch model, text comprehension is achieved through cycles and depends on the efficiency of different memories. During text processing, a restricted number of propositions is extracted from the surface of the text and treated in the working memory. Short-term memory stores information extracted from the surface level to generate the semantic level. Subsequently, the propositions are organised according to the arguments they share. Finally, they are integrated into the network of propositions already built and stored in the episodic memory. The network is updated at each cycle of processing until the end of the text. The situational model is thus progressively being built and regularly updated until the end of the text.

Text comprehension and aphasia

Several authors have demonstrated that the recall of microstructure is deficient in persons with aphasia (PWA) subsequent to left brain damage (Ferstl, Walther, Guthke, & von Cramon, 2005; Huber, 1990) whereas the recall of macrostructure is better preserved (Brookshire & Nicholas, 1984; Nicholas & Brookshire, 1995). Huber (1990), demonstrating that PWA can retain macrostructure, also showed that redundancy helps PWA understand texts; this suggests that these individuals must have sufficient detail to heighten their text comprehension (Huber, 1990). Conversely, other researchers (Lojek-Osiejuk, 1996) have demonstrated that PWA have a deficit that affects discourse macroprocessing but the texts used in their study included very few details. This is in keeping with the fact that some redundancy is necessary for PWA to access the macrostructure of a text. The capacity for the PWA to build a situational model seems to be preserved. PWA are able to use extralinguistic context to acheive an overall understanding; they can connect semantic information extracted from a text to expected information and general knowledge of the world (Hough, 1990; Huber, 1990).

These findings suggest that the semantic characteristics of texts are very important factors for PWAs' understanding of a text. Manipulation of semantic characteristics of the texts could be used as stimuli to test specific hypotheses with different populations. When we vary the semantic load (number of details) of the text, we change the cognitive load of the text. A text with a large number of micropropositions entails cognitive functions that are different from those required in the comprehension of a text with a small number of micropropositions or a text that requires situational model updating (Chesneau, Jbabdi, Champagne, Giroux, & Ska, 2007).

Aphasia and cognitive functions

Recently, there has been a growing realisation that PWA experience communication problems that extend beyond verbal deficits. These problems may be due not only to a faulty linguistic system but also to deficits that affect other cognitive functions required for communication. More specifically, several studies have revealed that cognitive processes, such as working memory (Caspari, Parkinson, LaPointe, & Katz, 1998; Mayer & Murray, 2012; Wright & Fergadiotis, 2012; Wright & Shisler, 2005), attention allocation and executive functions (Lambon Ralph, Snell, Fillingham, Conroy, & Sage, 2010; Purdy, 2002; Ramsberger, 2005; Wright & Fergadiotis, 2012) are impaired in PWA, indicating that the integrity of non-linguistic skills may play a role in successful communication. For example, Chiou and Kennedy (2009) have tested switching in PWA. Fourteen adults with aphasia matched with fourteen controls were asked to switch between Go/noGo rules with minimal linguistic and cognitive demands. The results demonstrate less accuracy and speed in PWA than in control participants. The authors have discussed these underlying processing deficits in a broader framework of cognitive flexibility, suggesting that the impaired reconfiguration and interference during switching identified in their study may be similar to processes to control and to inhibit thought and ideas. Thus, one can suppose that non-altered cognitive flexibility is needed to switch ideas to understand a text. For instance, the reader must be able to inhibit a situational model to build another one.

Based on the significant role of the semantic load and the involvement of the cognitive functions in text comprehension, the primary goal of the present multiple case study was to examine text comprehension by assessing the microstructure, macrostructure, and situational model updating in five participants suffering from left brain damage, who continued to complain about problems with text comprehension, although they did not have an objective linguistic comprehension impairment according to their clinical evaluations. We assessed the microstructure, macrostructure, and situational model updating using three texts with different semantic loads and with or without the need for situational model updating. We predicted that although the participants had recovered from linguistic deficits, the persons with left-brain damage (PWLBD) would experience difficulties with microstructure if the texts had a significant semantic load and with macrostructure if the texts had little redundancy. The PWLBD should be able to correctly update the situational model in the text as needed.

The second goal of the study was to examine the relationship between executive function and memory with text comprehension in PWLBD. Based on previous research, we predicted that PWLBD who had problems with microstructure or macrostructure in text requiring situational model updating would also have problems with executive functions and that the participants who had problems with microstructure and macrostructure in text with many details would have problems with long-term (episodic) memory.

Method

Participants with left brain-damage (PWLBD)

Six PWLBD were selected. Post-onset, they had demonstrated mild to severe symptoms of aphasia. However, at the time of testing, and according to their speech-language pathologist's conclusion after clinical assessment, all six participants had recovered from aphasia and no longer displayed any linguistic deficits. Nevertheless, all six participants continued to complain of discourse comprehension difficulties. They were right-handed and native French speakers (see participants' profiles in Table 1). The main criterion for inclusion in this study was that participants displayed text comprehension difficulties, regardless of the time elapsed since the stroke. Exclusion criteria were linguistic deficits at the basic level (phonology, morphology, syntax) as assessed by a standardised aphasia examination tool and visual exploration problems that could create reading difficulties.

(Table 1 about here)

Tests Used to Select and Gather Information on PWLBD

Boston Diagnostic Aphasia Examination (BDAE), French version (Mazaux & Orgogozo, 1981). The BDAE test evaluates the phonological, morphological, syntactic, and semantic aspects of the processes of language comprehension (word discrimination, commands, reading, and text interpretation) and language production (naming, repetition of words and phrases, and text production). The BDAE was used because there is no more sophisticated or specific test available to assess French speakers.

Participants' results in BDAE are provided in table 2.

(Table 2 about here)

Five of the six PWLBD selected for this multiple case study exhibited normal results on the BDAE. Only one participant failed to earn the maximum points in naming, repetition and complex ideational material sections of the test. We decided to exclude this person from the study.

Bells Test (Gauthier, Dehaut, & Joanette, 1989). The Bells Test evaluates visual exploration. It is a non-verbal test used to ensure that participants with a brain lesion have no visual neglect or visual exploration difficulties. The five PWLBD selected for this study exhibited normal results on this test.

Selected participants

P1: A 61-year-old female secretary experienced a left temporal haemorrhage 6 months before she was tested. She also presented a severe Wernicke's aphasia in the acute phase, although at the time of testing, no aphasia symptoms were observed in the clinical assessment.

P2: A 76-year-old nun experienced a left frontal ischemia in Broca's area 6 months before she was tested. She also experienced an anomic aphasia in the acute phase that was not detectable, using a standardized aphasia battery, by the time of testing.

P3: A 35-year-old woman experienced a left parieto-temporal ischemia 2 months before she was tested. Although she had also experienced mild conduction aphasia in the acute phase at the time of testing, her clinical assessment revealed no aphasic symptoms.

P4: A 60-year-old retired man experienced a left fronto-parietal ischemia 5 years before he was tested. Although he also experienced a global aphasia in the acute phase, clinical assessment at the time of testing revealed no aphasic symptoms.

P5: A 28-year-old-female artist (sculptor) experienced a left fronto-parietal aneurysm 10 years before she was tested. She also experienced a global aphasia in the acute phase, although clinical assessment at the time of testing revealed no aphasic symptoms.

These five participants complained of difficulties in text comprehension that had not been diagnosed with the clinical assessments available in French**.** All five persons were highly motivated to improve their language abilities, particularly their text comprehension abilities.

Control Participants

The five participants were compared to normative data for text comprehension and cognitive functions obtained in controls matched by age and educational level. These normative data were obtained from a previous study (Chesneau, Jbabdi, et al., 2007). The *young control participants* included 30 adults (N = 8 men, 22 women), ranging from age 21 to 40 (M = 27, SD = 5.8) with a mean of 16 years of formal education (SD = 1.5).

The *older control participants* included 30 adults (N = 9 men, 21 women), ranging from age 60 to 80 (M = 69, SD = 6.5) with a mean of 15 years of formal education (SD = 2.5). All participants had Mini-Mental State Examination (MMSE)(Folstein, Folstein, & McHugh, 1975) scores greater than 27, were right-handed native French speakers with normal or corrected vision and with no known history of dyslexia, stroke, psychiatric disease or other neurological disease.

Materials

Experimental Reading Task

Text comprehension was assessed using a task (Chesneau, Roy, & Ska, 2007) based on Kintsch's (1988) model to examine the macrostructure, microstructure, and updating of situational models, taking into account the semantic load of texts.

Ten texts were developed for the reading task: one training text and three series of three texts each. In each series, all three texts were different versions of the same story. Each text focused on the same theme but differed in two aspects: the number of details and the need for readers to update the situational model. In these texts, the situational model updating required modifiying the hypothesis made in the first three paragraphs of the texts about a plane crash, a car accident or a lost job and integrating new information – that what was being described was in fact a nightmare. A previous study conducted in two phases had enabled us to construct these texts. In the first step, 51 participants helped develop these texts. Each text series was designed to assess one level of discourse comprehension. During the second step 34 other participants ensured equivalence between the texts in each series. The results indicated that the texts of each series are equivalent, thus allowing an appropriate assessment of text comprehension (Chesneau, Roy, et al., 2007).

More specifically, in each series, one version of the story, called MICRO/SM, had a moderate number of details (90 semantic propositions represented by 249 words) which would require the reader to update the situational model. This version was designed to highlight a failure in situational model updating (Frederiksen & Stemmer, 1993). This first text, which constituted the reference for the next two versions, sits at the midpoint in terms of the number of details introduced. The following example (translated from French) is the first paragraph of a MICRO/SM text (the airplane story):

> *« Laura felt the plane ascending rapidly. It was a beautiful sunny day, the light wind having dissipated the haze that had covered the city earlier that morning. The pilot announced that the plane would fly northwest to Greenland, skirting England. From there, it would be only a few hours to New York, their destination.»*

The second version of the story, called *MICRO–/SM*, had fewer details (43 semantic propositions represented by 128 words) and similarly required updating the situational model. This version was designed to highlight a failure in the macrostructure processing. The need for readers to update the situational model was maintained to permit comparison with the first version. In Kintsch's model, the situational model depends on the macrostructure processing. The following example (translated from French) is taken from the first paragraph of the MICRO-/SM text (the airplane story):

« Laura felt the plane ascending. The pilot outlined the route that the plane would follow. It would only be a few hours before their arrival in New York. »

The third version of the story, called the *MICRO+,* had many details (135 semantic propositions represented by 341 words). However, updating the situational model was not required. This version was designed to highlight a failure in the microstructure processing as compared to the first version. To isolate the microstructure processing, it was unnecessary to update the situational model. Thus, the microstructure varied in each of the three versions, but the need to update the situational model only applied to two versions. The following example (translated from French) is the first paragraph of the MICRO+ text (the airplane story):

« Laura, a beautiful, charming young woman, was taking advantage of several days of holiday to leave Paris. She felt the plane ascending rapidly. It was May 23, and it was five minutes to two. She was comfortably seated in first class, a good novel within arm's reach. It was a beautiful sunny day, with not a single cloud darkening the sky. A light wind had dissipated the haze covering the city earlier that morning. The pilot, an experienced captain who had worked for a renowned airline company for 17 years, announced that the flight would veer to the northwest, skirting England and proceeding on to Greenland. From there, they would have a few hours of rest and relaxation before finally reaching their long-awaited, well-deserved destination: New York.»

To avoid the learning effect related to the content, each participant read one text from each series. One story describes an airplane crash, the second describes a car accident, and the third describes a lost job. In each series, the situational model needed to be updated in two of the texts because the last paragraph revealed that the entire story was a dream. These texts were inspired by the stories used in the study by Frederiksen and Stemmer (1993).

Each participant had to read the training text and three experimental texts—one from each series, each with a different form and content, without time limits (for details see procedure section). The macrostructure, microstructure, and updating of the situational model (for MICRO/SM and MICRO–/SM) were assessed for each text. The participants were asked to produce a condensed version of the text in the form of a summary to reconstruct the text's macrostructure. The choice to use a summary to measure the macrostructure ability was entirely dependent on the macrostructure's definition (see the introduction), inasmuch as the macrostructure must be extracted from the microstructure of the text by applying rules to condense, eliminate, or generalise micropropositions (Van Dijk & Kintsch, 1983). As validated in a previous study (Chesneau, Roy, et al., 2007), macropropositions correspond to the main ideas of the text. For example, "Laura's flight (to New York)" was one example of a macroproposition (translated from French) that could be expected from the first paragraph of the airplane text.

After the participants provided the summary, we used a questionnaire to measure their recall of text microstructure content. We asked questions about details that appeared in the text. The number of questions varied with each text, depending on the number of details. For MICRO/SM, 20 questions were asked to assess the microstructure; for the MICRO+ text, 30 questions were asked; and for the MICRO–/SM text, 12 questions were asked.

The following are examples of the questions asked about the first paragraph of MICRO/SM (the airplane story):

- What was the weather like when the plane took off?
- What was the weather like early that morning?
- Which route will the plane be following?
- Where will the plane be flying after England?

- What is the final destination of the trip?

For the MICRO/SM and MICRO–/SM texts, two questions were asked to assess the situational model updating. These questions were designed to reveal whether the reader had understood that the story was a nightmare and whether the reader had updated the situational model by changing the initial hypothesis of an actual flight to that of a dream.

Neuropsychological Tests

Executive functions (planning and flexibility) and memory functions (short-term memory, working memory, episodic memory) were evaluated via classical neuropsychological tests. We were able to choose these tests despite their language demand because our PWLBD showed no linguistic deficit likely to distort their performance.

The Digit span from the Wechsler Memory Scale – Revised (Wechsler, 1987) was used to assess short-term memory. The score is the higher accurate digit span.

The Alpha Span (Belleville, Rouleau, & Caza, 1998) was used to assess the storage and word manipulation in working memory. Participants were presented with 20 span-adjusted series of words that they were instructed to report either in the order of presentation or, after mental rearrangement, in alphabetical order. We noted the total number of recalled words after manipulation.

Episodic memory was assessed with two tests.

- The Buschke test (Buschke, 1973) was used to assess episodic memory. This test measures encoding and recall of words, and the score is the number of words recalled in delayed time.

- The first story from the Wechsler Memory Scale – Revised (Wechsler, 1987) was used to assess episodic memory. This test was the most similar to our experimental material. We noted the number of details recalled.

The Stroop Victoria (Regard, 1981) and Trail Making Test B (TMT) part B (Reitan, 1956) were used to assess executive functions (shifting and/or suppression). Stroop Victoria is a verbal version in which the participant must perform the following tasks: 1) read the names of colours, the words for which are printed in black; 2) name the colour of coloured circles; and 3) name the colour of the letters of printed words that name colours but are printed in another colour. We noted the time taken to accomplish the third task and the number of errors. For the TMT, the participants had to alternately connect letters and numbers as quickly as possible. Again, we noted the time taken and the number of errors.

The Tower of London (TOL) (Shallice, 1982) was used to assess executive functions (planning). The participant must move three rings from a starting position to a target position in a limited number of moves. The TOL consists of 10 individual items of increasing difficulty. We noted the accuracy (the total number of items accurately completed), efficiency (the total number of moves required for all the items to be completed accurately), and speed (the total number of seconds required for all the items to be completed accurately).

Procedure

All research procedures were approved by The Institut Universitaire de Gériatrie de Montréal Ethics Committee. Participants (PWLBD and controls) signed consent forms and received 20 Canadian dollars in compensation for each visit to the Institut Universitaire de Gériatrie.

Each brain-damaged participant was tested in two sessions that lasted approximately 90 minutes. Each session was conducted in a quiet room at the Institut Universitaire de Gériatrie de Montréal. During the first session, the participants completed the clinical language test (BDAE French version) and the visual exploration test (Bells), thereby fulfilling the inclusion and exclusion criteria.

The reading task was administered in the first part of the second session. The participants were informed that they must read four texts, without time limits, and respond to a questionnaire after each one. They read the training text first. The three experimental texts were subsequently presented in random order. The texts were presented in a 20-point font on the computer screen. The whole text appeared on the screen at once so that the participants could reread portions if they wanted. The participants read the text in silence. The examiner then asked the participants to summarise the text orally. Subsequently, the examiner read the questionnaire about microstructure aloud to the participants, one question at a time. This procedure was possible because the PWLBD no longer suffered from aphasic problems (Table 1). We recorded and transcribed the participants' responses to the questionnaires. During the second part of this second session, we administered neuropsychological tests according to the classical procedure.

Statistical Analyses

Because of the multiple case study design, we chose a descriptive method. Thus, we could not only compare each brain-damaged participant's performance with the results of healthy participants in his or her equivalent age group, but we could also compare individual performances on the different tests. Two reference groups were needed because the norms differed according to the age of the participants (Chesneau, Roy, et al., 2007). Given that the

PWLBD had different ages and education levels, we had to transform the raw scores. We calculated the *Z* scores for each brain-damaged participant. A participant's result was considered to be abnormal if it varied from the control group's mean by 1.5 standard deviations or more.

Results

The mean scores for the healthy population and the individual scores for the PWLBD are presented for each measure assessed in this study. Each brain-damaged participant's performance is subsequently compared with the results of his or her equivalent age group.

Text Comprehension

The PWLBD presented different profiles with regard to the text comprehension measures (see Table 3 for Mean scores and standard deviations for the Text Comprehension Measures for Healthy Young and Older Participants and Individual Scores).

Each PWLBD's performance on text comprehension was compared with the results of his or her equivalent age group. Table 3 displays the *Z* scores for the text comprehension measures in PWLBD. However, the Z scores could not be calculated for the macrostructure results for the two young PWLBD because the young control participants completely grasped the macrostructure of all the texts.

(Table 3 about here)

P1 had problems with the two texts that contained details (moderate or large numbers of semantic propositions). She was unable to recall correctly either the macrostructure or the microstructure of MICRO/SM and MICRO+, and she was unable to update the situational model of MICRO/SM.

P2 had difficulties with the text that had a moderate number of details (moderately loaded with semantic propositions) and required readers to update the situational model. She was unable to recall correctly the microstructure of MICRO/SM.

P3 had problems with the text that had some details (moderately loaded with semantic propositions) and required readers to update the situational model. She was unable to recall correctly the macrostructure or to update the situational model of MICRO/SM. In addition, she was unable to recall correctly the microstructure of the text MICRO–/SM, which had fewer details (underloaded with semantic propositions).

P4 had difficulties with the text that contained the most details (overloaded with semantic propositions) and the text that had the fewest details (underloaded); he was unable to recall correctly either the macrostructure of MICRO+ and MICRO–/SM or the microstructure of MICRO–/SM.

P5 had problems with the text that had the most details (overloaded) she was unable to recall correctly either the microstructure or the macrostructure of MICRO+.

In summary, four PWLBD (P1, P3, P4, P5) were unable to recall correctly the macrostructure in one or several texts; two PWLBD (P1 and P3) were unable to update the situational model in MICRO/SM, and none of the participants was able to recall correctly the microstructure.

Memory

The scores for each healthy group were within the range of the corresponding age norms. The PWLBD presented different memory profiles. Table 4 displays the mean scores for the memory measures for healthy young and older participants and the individual scores for the PWLBD. Each PWLBD's performance on the memory measures was compared with the results of his or her equivalent age group; the *Z* scores were subsequently calculated for each participant. Table 4 displays the *Z* scores for memory measures in the PWLBD.

(Table 4 about here)

P1 was weak in short-term memory, working memory, and episodic memory (tested with the first story from the Wechsler Memory Scale). **P2** was weak in short-term memory and episodic memory (tested with The Buschke test and the first story from the Wechsler Memory Scale). **P3** and **P4** were only weak in short-term memory. Finally, **P5** was weak in short-term and episodic memory of words (tested with The Buschke test).

Executive Functions

The scores of each healthy group were within the range of the corresponding age norms. However, the PWLBD presented different profiles on the executive function measures. Table 5 displays the mean scores for the executive function measures in healthy young and older participants and the individual scores for the PWLBD. Each PWLBD's performance relative to executive function was compared with the results of his or her equivalent age group. The *Z* scores were calculated for the executive function measures for each PWLBD. Table 5 displays the *Z* scores for the executive functions in PWLBD.

(Table 5 about here)

All PWLBD performed normally on the TOL. **P1** had normal performance on the Stroop, TMT, and TOL tests. All other PWLBD performed below normal on the Stroop test; one (**P5**) performed below normal on the TMT.

Text comprehension and ***cognitive functions***

In the current study, a variety of tasks was choosen to represent different sub-processes within memory and executive functioning in an attempt to capture the complexity of the construct of text comprehension in PWLBD. Table 6 illustrates that a complaint of text comprehension may correspond to different underlying deficits that affect text comprehension representation levels, memory, or executive functions.

(Table 6 about here)

These results suggest that different patterns of memory and executive function underlie different text comprehension deficits in our PWLBD.

Discussion

This multiple case study was designed to investigate text comprehension and cognitive function in five participants suffering left brain damage who were complaining about text problems. This multiple case study revealed two key findings. First, the complaint about text comprehension problems can be objectified, with several texts in which the semantic load varies. Second, the same subjective complaint could correspond to different underlying deficits that affect text comprehension representation levels, memory, or executive functions.

Text comprehension and characteristics of the text in residual aphasia

The text comprehension assessment noted several deficits for each participant related to the characteristics of the texts. Moreover, each participant presented a particular text comprehension profile. Two participants displayed below-normal macrostructure recall for a text with many details that required them to update the situational model (MICRO/SM). These two participants did not update the situational model. One displayed below-normal macrostructure recall with the text overloaded with details (MICRO+), and the other exhibited below-level recall with the text underloaded with details and that required the reader to update the situational model (MICRO–/SM) as well as with the text overloaded in details (MICRO+). All our five PWLBD had a microstructure recall below normal for one or two of the texts.

These findings reveal that the comprehension profiles of the five PWLBD of our study are related to the semantic load of the text (few or many details) and to the need for the reader to update the situational model. The literature on text comprehension suggests that persons with aphasia perform worse than healthy controls on microstructure recall but normally on macrostructure and situational model recall (Ferstl et al., 2005; Huber, 1990; Nicholas & Brookshire, 1995). Although text characteristics (microstructure and macrostructure) were controlled in these studies, the semantic load (number of semantic propositions) was always the same and was never manipulated. In the present study, two PWLBD unexpectedly displayed difficulties not only with microstructure and macrostructure recall but also with situational model updating. These participants were likely overtaxed with semantic propositions when reading a text with details and the necessity to update the situational model. The number of propositions to process may have exceeded their cognitive resources so that the additional task of updating could not be performed. Indeed, the two participants' (P1 and P3) success in situational model updating when reading a text that required them to update the situational model but which was underloaded with semantic propositions tends to confirm this hypothesis. The cognitive demand made by the different representation levels of text comprehension or by the transition from one level to another seems dependent on the text's characteristics. Similar findings were obtained in an earlier study of text comprehension in normal aging (Chesneau, Jbabdi, et al., 2007). These results are coherent with resource allocation models of discourse comprehension (McNeil, Odell, & Tseng, 1991).

Despite the small number of participants included in this study, this finding suggests two clinical impacts in the assessment of text comprehension. First, it confirms the importance of using texts in which semantic load and situational model updating are controlled. Second, it confirms the necessity of using multiple texts in which semantic load varies.

Furthermore, this protocol enabled us to objectify text comprehension deficits that were not revealed using a classical clinical assessment. For persons who have residual aphasia, this protocol constitutes an important point of this research and argues for pursuing additional therapy.

Text comprehension and cognitive function in residual aphasia

We investigated the different types of memory in Kintsch's (1988) model of text comprehension as well as the executive functions that may be impaired in PWLBD (Keil & Kaszniak, 2002). In contrast to our predictions and to several findings of Ferstl et al. (2005), our results revealed an episodic memory deficit in only three participants who exhibited difficulties with microstructure or macrostructure. Although this finding does not refute the episodic memory implication for text comprehension, it demonstrates that episodic memory is not the only memory associated with text comprehension. For instance, our PWLBD displayed a short-term memory deficit, which was manifested by a reduced span in all five persons. These results are consistent with Martin, Shelton, & Yaffe (1994)'s multiple components model of short-term memory in which semantic and phonological components play different roles in language processing, particularly in sentence comprehension. These authors observed that the semantic component of short-term memory is critical for comprehension while the phonologic component is crucial for repetition. This suggests that the short-term memory deficit of the PWLBD who had no difficulty in repetition (see Table 2) might involve the semantic component. Martin et al. (1994)'s model could then account for the results of our participants who did not perform well in overloaded texts.

Four participants had no working memory deficit (no manipulation deficit), as confirmed by normal results on the Alpha Span. Our findings contrast with those of Caspari et al. (1998), who explained that reading comprehension deficits resulted from a working memory deficit that affects the manipulation component. Most authors who link text comprehension or syntactic comprehension to a working memory deficit have focused their studies on working memory and did not control for the implication of other cognitive deficits (Caplan & Waters, 1995; Caspari et al., 1998; Francis, Clark, & Humphreys, 2003; Ikeda, 2013). Our study indicates that text comprehension can be impaired when an association of cognitive functions is impaired, including working memory.

In the present study, the PWLBD displayed a short-term memory deficit and a text comprehension deficit. However, none had an isolated short-term memory deficit. Indeed, one participant displayed a concomitant working memory and episodic deficit. Three other participants presented episodic memory deficits associated with short-term memory deficit.

This multiple case study, which included individuals with residual aphasia in whom no linguistic disorder can be detected, highlights the involvement and the complex interactions of the different types of memory during text comprehension. Each text comprehension deficit seems to result from the association of different memory deficit and may be the outcome of the association of a variety of other cognitive deficits, including those that affect the executive functions.

An important number of studies evaluate the effect of executive functions on aphasic subjects' performance of cognitive tasks (Fridriksson, Nettles, Davis, Morrow, & Montgomery, 2006; Purdy, 2002; Ramsberger, 2005). Intact executive functioning appears necessary for an adequate response to new and complex environmental demands.

In the present study, three tasks (TOL, Stroop, TMT) were chosen to assess different executive functioning processes in the five participants who had complained about text comprehension. These tasks were choosen because the five PWLBD had no more linguistic deficit. The TOL was used to address goal-directed planning. The PWLBD performed this task with the same accuracy, efficiency, and speed as the healthy participants. Given this result, the comprehension problems of PWLBD cannot be explained by a planning deficit. The Stroop and TMT tasks were used to address cognitive flexibility. The PWLBD had difficulties with the Stroop task. One participant also had difficulties with the TMT. These findings replicate Purdy's (2002) and Fridriksson (2006) results, which identified deficits that affect cognitive flexibility. One possible hypothesis is that a cognitive flexibility deficit in these five PWLBD influenced their text comprehension. However, this cognitive deficit did not occur in isolation, as these participants also presented different memory deficits.

Consequently, the observed text comprehension problems must be related to a combination of cognitive deficits and not simply to one specific deficit. Although participants with text comprehension complaints demonstrated several difficulties with different types of memory in addition to cognitive flexibility, caution should be used when generalising this observation to other individuals with text comprehension deficits. Furthermore, our study does not indicate whether the various processes involved are related. Variability in the different patterns of texts comprehension may be due to the highly heterogeneous characteristics of participants who presented with diverse brain injury locations, various types of aphasia at the acute stage and varying times and duration of post-onset assessment.

In conclusion, text comprehension relies not on language-specific processes alone but on other non-linguistic and cognitive processes as well. These findings have implications for cognitive interventions that target reading comprehension abilities after brain damage, regardless of whether a linguistic deficit is present. This conclusion emphasises the importance of assessing text comprehension using several texts that vary in semantic load and in their need for readers to update the situational model. However, further research is needed in larger and more homogeneous PWA groups in order to link the different cognitive profiles with the text comprehension profiles.

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Table 1

Demographic and Clinical Features of Persons with Left Brain Damage

Participant	Age years	Gender	Education years	Time post-onset	Neurological information	Aphasia type post-onset	Aphasia symptoms at time of testing
P1	61	F	12	6 months	Hemorrhage: Left temporal	Severe Wernicke's aphasia	None
P2	76	F	10	6 months	Ischemia: Left frontal in Broca's area	Anomic aphasia	None
P3	35	F	14	2 months	Ischemia: Left parieto-temporal	Mild conduction aphasia	None
P4	60	M	16	5 years	Ischemia: Left fronto-parietal	Global aphasia	None
P5	28	F	11	10 years	Aneurism: Left fronto-parietal	Global aphasia	None

Table 2

Results of the patients with brain damage to Boston Diagnostic Aphasia Examination (BDAE, French Version) (Mazaux & Orgogozo, 1981)

	P1	P2	P3	P4	P
Word Discrimination	72/72	72/72	72/72	72/72	72/
Commands	15/15	15/15	15/15	15/15	15/
Complex Ideational Material	12/12	12/12	12/12	12/12	12/
Repetition of Words	10/10	10/10	9/10	10/10	10/
Repeting Phrases (High Probability)	8/8	8/8	8/8	8/8	8/
Repeting Phrases (Low Probability)	8/8	8/8	8/8	8/8	7/
Visual Confrontation Naming	105/105	105/105	105/105	105/105	105/
Reading Sentences and Paragraphs	10/10	9/10	10/10	9/10	10/

Table 3

Mean Scores (percentage of correct responses), Standard Deviations (SD) for the Text Comprehension Measures for Healthy Young and Older Participants and Individual Scores and Z-Scores for persons with left brain damage (PWLBD)

Participants		MICRO/SM		MICRO+		M
		Macrostructure	Microstructure	Macrostructure	Microstructure	Macrostruct
Healthy	Young	100	81 (6.6)	100	80 (11.2)	100
	Older	99 (5)	74 (13.2)	99 (5)	66 (11.2)	97 (8)
Persons with left brain damage	P1*(O)	40	45	75	37	100
	Z-score	-11.6	-2.2	-20.5	-2.7	0.4
	P2 (O)	100	45	100	50	100
	Z-score	0.2	-2.2	0	-1.5	0.4
	P3*(Y)	60	80	100	70	100
	Z-score	#	-0.2	0	-0.9	0
	P4 (Y)	100	75	75	60	80
	Z-score	0.2	0	-5.3	-0.6	-2.2
	P5(Y)	100	90	75	50	100
	Z-score	0	1.3	#	-2.7	0

Note: * Participants who did not update the situational model in MICRO/SM, (O) old participant, (Y) young participant

#: Impossibility of calculating the Z score because the results of the reference population (100%).

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Healthy	Young	14.7 (1.1)	7.3 (0.7)	35.2 (7.9)

	Older	13.6 (1.6)	6.8 (1)	31.5 (5.7)
Persons with left brain damage	P1 (O)	14	4	21
	Z-score	0.2	-2.7	-1.8
	P2 (O)	4	4	27
	Z-score	-6.2	-2.7	-0.1
	P3 (Y)	15	3	27
	Z-score	0.3	-5.8	-1
	P4 (O)	13	4	28
	Z-score	-0.4	-2.7	-0.6
	P5 (Y)	11	4	27
	Z-score	-3.5	-4.4	-1

Note: No.: number; (O) old participant, (Y) young participant

Table 5

Mean Scores and Standard Deviations (SD) for the Executive Function Measures in Healthy Young and Older Participants and Individual Scores and Z-Scores for persons with brain damage.

Participants		Stroop Speed (seconds)	Stroop Errors	TMT Speed (seconds)	TMT Errors	TOL Accuracy	TOL Efficiency	TOL Speed (seconds)
Healthy	Young	20 (4)	0.3(0.6)	60 (16)	0.1 (0.3)	11.9 (0.2)	67.6 (10)	228 (86)
	Older	31 (10)	0.9 (1.6)	108 (45)	0.6 (1.0)	11.9 (0.4)	69.6 (12)	322 (112)
Persons with Left brain damage	P1 (O)	40	0	87	0	12	70	412
	Z-score	0.9	-0.5	-0.5	-0.6	-0.3	0	-0.8
	P2 (O)	46	2	153	0	12	71	335
	Z-score	1.5	0.7	1	-0.6	-0.3	- 0.1	-0.1
	P3 (Y)	26	4	81	0	12	72	270
	Z-score	1.5	6.4	1.3	-0.4	-0.5	-0.4	-0.5
	P4 (O)	59	0	155	0	12	70	301
	Z-score	2.8	-0.5	1	-0.6	-0.3	0	-0.2
	P5 (Y)	47	4	115	0	12	64	127
	Z-score	6.4	6.4	3.3	-0.4	-0.5	0.4	-1.2

Note: (O) old participant, (Y) young participant, TMT: Trail Making Test, TOL: Tower of London

Table 6

Text Comprehension and Neuropsychological Deficits of the persons (P) with left brain damage.

Texts Comprehension Deficits	Neuropsychological Deficits

	MICRO/SM		MICRO+		MICRO–/SM		Memory			Executive functions		
	Macro	Micro	Macro	Micro	Macro	Micro	Short term	Working	Episodic	Flexibility (stroop)	Flexibility (TMT)	Planning
P1	*	*	*	*			*	*	*			
P2		*		*			*		*	*		
P3	*					*	*			*		
P4			*		*	*	*			*		
P5			*	*			*		*	*	*	

Note:
* = disturbed
MICRO/SM: Text semantically loaded with the necessity to update the situation model
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P4			*		*	*	*			*		
P5			*	*			*		*	*	*	

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