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PÓS-GRADUAÇÃO EM LETRAS/INGLÊS E LITERATURA CORRESPONDENTE

THE IMPACT OF AGING AND LANGUAGE PROFICIENCY ON THE

INTERHEMISPHERIC DYNAMICS FOR DISCOURSE PROCESSING:

A NIRS STUDY

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Abstract

The Impact of Aging and Language Proficiency on the Interhemispheric Dynamics

for Discourse Processing: A NIRS Study

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The study of the bilingual and of the aging brain has the potential to offer important evidences for our understanding of the cerebral dynamics for language processing. There is a special need of studies to investigate discourse processing by these populations. In this study, intermediate-proficiency bilinguals (English as L1 and French as L2) and elderly individuals' narrative processing at the micro-, macro-structural and situational levels were investigated, by the application of near-infrared spectroscopy (NIRS). Participants read narratives followed by probes, which tapped one of the three levels, and judged the plausibility of their information by reference to the corresponding passage. The findings brought by the study suggest the possibility of the application of similar theoretical approaches to explain language processing in these two

populations. Although emerging from different reasons (aging or low proficiency in the L2), the deficits or limitations brought to language comprehension generate some comparable inter-hemispheric patterns in brain hemodynamics (for instance that of more relevant, wider and in some cases bilateral hemodynamic changes), which are compatible with the theoretical framework proposed by Banich and colleagues. Thus, it seems to be arguable that in both populations the hemispheres tended to cooperate and share the costs for task processing, or demanded an increased activation in the recruited area in order to accomplish the task. Similarly to the assumptions made by the model, it seems to be plausible to state that the increase of activation within a region and/or the interhemispheric contributions were positively correlated to the amount of task difficulty.

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Resumo

O estudo do cérebro bilíngüe e em fase de envelhecimento pode trazer evidências importantes para nossa compreensão da dinâmica cerebral no processamento lingüístico. Há uma necessidade de se implementarem estudos que investiguem o processamento do discurso por estas populações. Neste estudo, investigou-se o processamento de narrativas em seus níveis micro-, macro-proposicional e situacional por bilíngües de proficiência intermediária na língua estrangeira (L1 inglês e L2 francês) e por indivíduos idosos. Os participantes leram narrativas seguidas de asserções as quais comtemplavam um dos três níveis do discurso e julgavam a plausibilidade da informação apresentada na asserção com referência ao texto correspondente. Os resultados trazidos pelo estudo sugerem a possibilidade da aplicação de abordagens teóricas similares para explicar o processamento lingüístico nestas duas populações. Embora originadas por diferentees razões (envelhecimento ou reduzida proficiência na segunda língua), as deficiências ou limitações trazidas à compreensão da linguagem geram padrões comparáveis nas mudanças hemodinâmicas no cérebro (por exemplo, mudanças hemodinâmicas mais significativas, difusas ou em alguns casos bilaterais), as quais parecem poder ser explicadas através do mesmo enquadramento teórico, proposto por Banich e colegas. A partir dos dados, parece plausível afirmar-se que, em ambos os grupos, os hemisférios tenderam a cooperar e dividir os custos impostos pelo processamento da tarefa, ou solicitaram uma mais prominente ativação na área recrutada para executar a tarefa. De modo semelhante ao que é postulado pelo modelo, um aumento na ativação em uma

região e/ou as contribuições entre os hemisférios foram positivamente correlacionadas ao nível de complexidade da tarefa.

Table of Contents

List of tables

List of figures

CHAPTER 1

INTRODUCTION

Language is one of the most fascinating and complex components of human cognition, a characteristic that distinguishes human beings in terms of their capacity of communicating and reasoning. In its ordinary use in everyday communication, language seems to be simple and effortless on its surface; however, it has been exactly this simplicity that has imposed so much difficulty to its study and understanding, as pointed by Mazoyer et al. (1993, p. 467).

Our language system is a complex network composed by multiple levels of analysis, each one in its own turn being intrinsically very complex as well. The different components that form our language system are phonology, syntax, morphology, semantics, discourse and pragmatics. Since there is still much research needed to understand each of these components in their integrity, the study of discourse, a component formed by the junction of all the others in naturalistic language use, has turned to be one of the most challenging.

The comprehension of a text is dependent on the reader's capacity of identifying and understanding its linguistic components, from simple letters to entire sentences and strings of sentences, which contain semantic and syntactic binding elements. Meaning must be interpreted literally and, sometimes, also figuratively, in this case demanding the reader to make inferences by referring to his/her world knowledge. The concurrence

of these abilities explains the variability sometimes existing in terms of text comprehension among different people. Moreover, other factors, such as aging and language proficiency, in the case of reading in a second language, may also cooperate to the emergence of individual differences in reading. That is, regarding aging, it is known that changes in cognitive and sensorio-motor processes may happen, resulting in different patterns of behavioral and cerebral responses, the same happening in relation to low-proficient L2 (second language) readers, whose cerebral organization seems to be differently distributed from the native speakers' ones, as it will be discussed.

Much research has been developed in the field of neurolinguistics in the past decades and, thanks to the evolution of imaging techniques, important findings have emerged, helping us unveil language functioning in the human brain. For instance, neuroimaging studies have linked dorsolateral prefrontal regions to working memory, superior parietal regions to attentional functions and medial temporal regions to the acquisition of new declarative memories (Banich & Weissman, 2000). In the specific case of discourse processing, much is still to be investigated in order to reach a deeper understanding of how the brain processes a text, since the majority of the imaging tools available in the market impose certain restrictions to this type of study. Along with fMRI and PET (see a brief introduction to these tools below), a new imaging tool, NIRS (Near-Infrared Spectroscopy) seems to be a reliable tool to test the neural basis of language functioning, with a special advantage for discourse studies, since this non-invasive technique allows the research participants to read texts in a more naturalistic way.

Due to the complexity of discourse processing itself and to the advent of the investigation of language (and especially of discourse) with imaging techniques being recent, with the techniques being incremented little by little, several issues regarding discourse processing in the brain are still ill-known.

This study has investigated discourse processing with NIRS, specifically in two populations: elderly adults and bilinguals, in order to analyze their patterns of behavioral response (in terms of accuracy and response time) and of cerebral hemispheres responses. This comparison may provide insights for an understanding of the issues involved in the complex dynamics which occurs within and among the two cerebral hemispheres during the reading process.

1.1 STATEMENT OF THE PROBLEM: DISCOURSE PROCESSING IN BILINGUALISM AND IN AGING

The neurobiological bases of discourse processing are ill-known, once only a reduced number of studies have already focused on this issue. Moreover, the influence of aging and of L2 proficiency on the nature of the intra- and inter-hemispheric dynamics is also unknown; that is, there is a need of studies to investigate how the hemispheres engage for reading and comprehending a text, considering different textual levels of complexity, by elderly and by bilinguals. For both aging and low L2 proficiency, current models (HAROLD – for aging - and the Banich Model – applicable to investigate the effect of language proficiency – both to be discussed) would predict an

increase in right hemisphere's (RH) participation, thus suggesting that these two models reflect similar basic mechanisms.

Thus, the major aim of this study is to investigate how narrative discourse is processed in its different levels (micro-, macro-structure and situational model) by younger and older adults, as well as by bilinguals with an intermediate proficiency in their L2 (second language). The investigation will be two-fold: behaviorally, it presents and discusses data on accuracy and response time, while the use of NIRS aims to elucidate the interhemispheric dynamics that take place when these populations process the different levels of narrative processing.

1.2 INTRODUCING NIRS (*NEAR-INFRARED SPECTROSCOPY*)

A variety of non- or minimally-invasive neuroimaging techniques for investigating brain functioning is available to researchers. The methods are categorized according to their level of invasiveness and to their direct or indirect ability to provide information about brain functioning (Strangman et al., 2002). Within the direct methods, MEG (magnetoencephalography) records the magnetic field generated by neuronal activity, while EEG (eletroencephalography) and ERPs (event related potentials) record electrical fields generated during processing. The indirect methods, such as PET (positron emission tomography), SPECT (single-positron emission computed tomography) and fMRI (functional magnetic resonance imaging), monitor hemodynamic changes

resulting from brain electrical activity. Each technique has its advantages and drawbacks.

Up to now, the direct methods tend to have limited spatial resolution, whereas the indirect methods "can only detect neuronal activity after it has been filtered by a complex and poorly-understood neurovascular coupling function" (Strangman et al., 2002, p. 679). MEG and ERPs have very good temporal sensitivity but relatively poor spatial sensitivity, while fMRI, SPECT and PET are stronger at spatial sensitivity but poorer in terms of temporal resolution.

A lesser-known technology - NIRS (near-infrared spectroscopy), also called optical imaging (OI), near-infrared optical topography (NIROT) or diffuse optical tomography (or topography) (DOT) – has emerged as a promising tool for measuring the cerebral blood volume dynamics closely correlated to the neuronal activity. Compared to the other methods, it has an excellent temporal sensitivity and a reasonable spatial resolution. It is a non-invasive technique which measures the concentration of oxyhemoglobin, desoxyhemoglobin and the total hemoglobin, which is proportional to blood volume. The technique basically consists of shining infrared light onto the scalp (through the sources) and detecting it (through the detectors) as it exits the head. In its passage heading to the cortical area of the brain, the light draws a banana-shaped curve, where the blood dynamics is analyzed (see Figure 1).

Fig 1: Representation of how the NIRS infra-red light propagates within the brain (source: CRIUGM_analyses_NIRS)
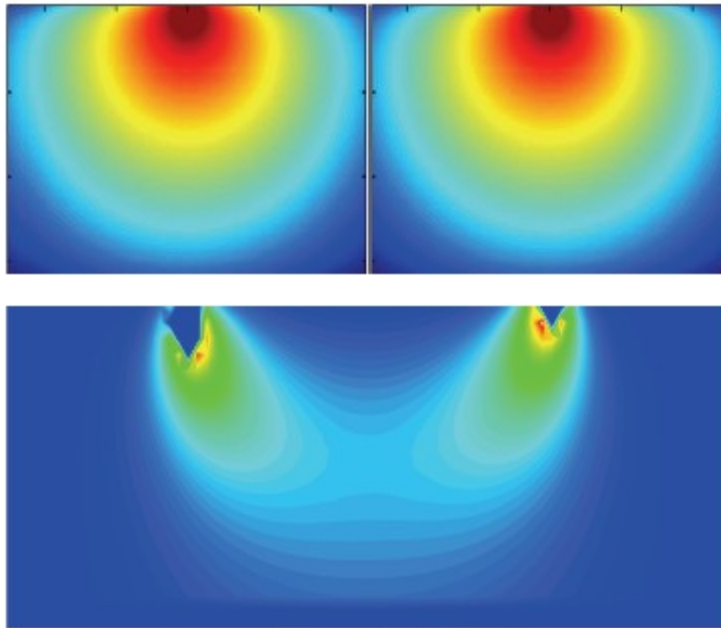
Parameters can be measured with a penetration depth of about 2cm from the scalp and a spatial resolution of about 0.5 cm (Quaresima et al., 2002). Light penetration can vary according to the position of detectors and sources of light, being this distance advisable to remain between 3 and 6 cm at maximum.

A variety of NIRS equipment is commercially available, based on different NIRS methods, being the choice determined by the type of the requested information (see Ferrari et al., 2004 for a review on main NIRS instruments).

Due to their influence in the amplitude of the recorded signal, two critical aspects have to be monitored for data analyses: absortion of light by the tissue and light scattering within the tissue. Absortion changes are basically generated by hemoglobin concentrations, while scattering changes are more difficult to interpret, since they may vary, for example, due to the existence of brain regions with higher dense fiber tracts,

which vary among individuals or evolve over time (Strangman et al, 2002, p. 681). Presently, most research assumes that scattering remains essentially constant all over the experiment and that the changes in signal are due to changes in absortion. To calculate and quantify changes in concentrations of absortion, researchers apply the modified Beer-Lambert Law (MBLL), "which empirically describes the optical attenuation in a highly scattering medium" (Cope et al., 1987, in Strangman et al., 2002, p. 684) (for detailed explanations on how this equation is applied, see Strangman et al., 2002, and Villringer & Obrig, 2002, p. 143).

The pioneering work of Jobsis (1977) has first used NIRS to investigate brain oxygenation, and in the last decade the technique has largely investigated the functional activation of the human cerebral cortex (see Obrig & Villringer, 2003, for a review). Functional NIRS has the potential of giving a unique contribution to human brain mapping studies considering that it has several advantages over existing technologies. Among these advantages, one can mention the following:

- The technique is resistant to the motion artifact enabling the measurement done in living circumstances such as a sitting position (Watanabe et al, 1998, p. 49), and even performing movements like walking, in the case of the wireless prototypes under development. Moreover, it is possible to detect overt verbal responses which would provoke artifacts in fMRI results (Quaresima et al., 2002, p. 241).

- The instrumentation is portable, unobtrusive, has low cost and low power consumption. It allows measurements in a natural environment.

- As it is non-ionizing, there is no limit to the number of scans one can undergo.

- The technique permits to independently measure the temporal changes in [HbO] (concentration of oxyhemoglobin), in [HbR] (concentration of deoxyhemoglobin) and [HbT] (concentration of total hemoglobin).

- There is no noise associated with this technique which could interfere with the auditory stimuli and with the participants' attention to the task.

- It has a high temporal resolution, better than fMRI's, and its reduced spatial resolution as compared to fMRI can be compensated by the co-application of other measures, such as anatomic MRIs and/or the use of the 10 x 20 system (Jasper, 1958) to locate the probes.

The technique has three major drawbacks: with the models currently available, measurements are restricted to the cortical surface; the spatial accuracy is limited (although coupling the technique with other procedures, as already mentioned, may reduce this tradeoff), and the interference of extracranial artifacts such as hair color and density must carefully be evaluated (Quaresima et al, 2002, p. 241).

1.3 SIGNIFICANCE OF THE STUDY

Data obtained by studies on language processing by bilinguals may aid a wide range of domain fields, such as L2 teaching and learning, language translation, phonoaudiology, speech pathology, language therapy, among other areas. For instance,

in the field of second language teaching / learning, the data may contribute to our understanding of the processes underlying language learning in initial stages of acquisition, by bringing evidence on how the L2 gets structured and evolves in the learning brain. Moreover, considering that nowadays more than half of the world's population is multilingual (Grosjean, 1994), such studies reflect not the exception but a good representation of the phenomena undergoing cerebral activity in language computation.

Similarly, as the world population's life expectancy levels become higher, a greater concern has been given to aspects related to cognitive processes in aging, including language production and comprehension. Special attention should be given to reading, which constitutes an important habit to maintain higher levels of cerebral activity, and fortunately represents one of the favorite activities of elderly people, especially among those with a higher level of education. The study of normal and impaired language faculty in aging (in this context, of the comprehension of written texts by non-brain-damaged elderly adults) may give us an important portrait of the processes underlying the aging brain.

To sum up, the study presented in this dissertation can be considered innovative for the following reasons:

- ❖ the lack of studies on discourse processing which combine both imaging and behavioral data;

- ❖ an even more reduced number of a combined behavioral and imaging research on discourse processing in bilingualism and in aging;

❖ the lack of understanding of the role of the cerebral hemispheres in processing the different textual levels (micro- and macro-structure and situational level);

❖ the still reduced understanding of the factors determining the hemispheric "coupling and de-coupling" (terms used by Banich, 2002) during the reading process in aging and in bilingualism ;

❖ the application of a relatively new imaging technique, NIRS/OI (its application to language studies has started in the 1990s), which has demonstrated to be a promising tool for studying brain activity.

Thus, the development of this dissertation may be relevant for investigating the nature of cerebral hemispheres' collaboration in discourse processing, in two populations who have much to teach us about the cerebral dynamics, namely elderly individuals and bilinguals. Moreover, its relevance consists of applying in a discourse study an imaging technique which has not been used yet for this type of investigation.

1.4 OBJECTIVES AND HYPOTHESES

1.4.1 General objectives

The aims of this study are basically two: (1) to investigate the influence of aging on the nature of the interhemispheric dynamics in discourse processing, by analyzing the neurobiological bases of this process in younger and older adults, through the use of

NIRS, and (2) to investigate the influence of a lower level of L2 proficiency on the nature of the interhemispheric dynamics in discourse processing, by analyzing the neurobiological bases of this process in proficient and non-proficient younger adults, through the use of NIRS.

The specific aims of the study are to describe more clearly the impact (1) of aging and (2) of lower level of L2 proficiency on the processing of micro- and macro-propositional levels and situational aspects of the narrative discourse, by examining the influence of age and of low L2 proficiency in the relative contribution of the two hemispheres to the processing of discourse.

1.4.2 Hypotheses

The hypotheses are presented by area of investigation (bilingualism and aging) and by type of data (behavioral and imaging). The hypotheses refer to the expected performance of the three groups under investigation: 10 young adults, French native speakers (YF), the control group, whose performance will be compared to that of the 10 elderly adults' group, also French native speakers (EF), and to that of the 10 young English native speakers' group (YE), with an intermediate proficiency in French as L2.

Hypotheses concerning behavioral results:

a) For elderly participants' processing:

HYPOTHESIS 1: Regarding accuracy, it is expected that, when compared to young participants (YF), aged participants (EF) will show lowered performance at processing micro-level propositions (MIC), whereas they will show similar performance when processing macro-propositions (MAC) and the situational (SIT) model. More specifically, it is expected that <u>older participants</u> will have <u>lower scores at their micropropositional analysis</u> as compared to the younger participants' scores, but similar scores in relation to MAC and SIT processing.

HYPOTHESIS 2: Elderly participants (EF) will show <u>higher response times in average for the three conditions</u> when compared to the group of young French speakers (YF).

b) For lower proficiency level participants' processing:

HYPOTHESIS 3: Non-proficient young adults, English native speakers (YE), will show lowered performance, that is, more incorrect responses in the three conditions as compared to young French native speakers' performance; their scores will be lower at processing MAC and SIT levels than at MIC processing.

HYPOTHESIS 4: Non-proficient young bilinguals (YE) will show higher response times for all the three levels of L2 text processing as compared to young French native speakers' performance (YF).

Hypotheses concerning imaging results:

a) For elderly participants' processing:

HYPOTHESIS 5: An increased and more diffuse loci of activation in both hemispheres is expected in aged participants (EF) in all three levels; more specifically, it is expected that the SIT and MAC analyses will reflect higher frontal activation, especially in the RH, as compared to younger adults French speakers (YF), and that bilateral activation in older adults is expected for MIC processing.

b) For lower proficiency level participants' processing:

HYPOTHESIS 6: An increased and more diffuse loci of activation in both hemispheres is expected in non-proficient participants (YE), very pronounced in the RH as compared to young adults native-speakers (YF), in all three levels of text processing, especially in MAC and SIT levels; more specifically, it is expected that all levels of analyses will involve increased activation and more diffuse temporal and frontal sites of activation, detectable with NIRS, and that the diffusion and activation will be higher in the RH in non-proficient participants' performance.

1.5 ORGANIZATION OF THE DISSERTATION

In order to reach the objectives proposed by the study, the dissertation has been organized in five main parts.

Chapter 1, the introduction, presented the context of the investigation, the importance, aims and hypotheses of the study, as well as an overview of the main features of the imaging tool utilized.

Chapter 2 presents the state of the art of the two main issues focused in the dissertation: discourse processing in aging and in bilingualism, starting with a discussion on discourse processing in general, to further relate it to the specific cases of bilingualism and aging.

Chapter 3 presents issues related to the method adopted in the investigation, carried out through the application of a battery of neuropsychological tests, and through the behavioral and neuroimaging studies developed. This part will describe the participants' characteristics, the material, as well the procedures for data collection and analyses.

Chapter 4 presents and discusses the results obtained in the three test modalities (neurological, behavioral and imaging testing).

Chapter 5 presents some conclusions based on the discussions developed in the dissertation, the limitations of the study, some suggestions for further research as well as some final remarks.

Throughout the dissertation, some abbreviations will be used. They will be presented in full at least once in the text but, to facilitate access to their meaning, Table 1, below, presents a list of the terms used.

Table 1: List of acronyms and terms

Acronym or term	Meaning
AoA	Age of L2 acquisition
EF	Elderly French native speakers
fMRI	Functional magnetic resonance imaging
FI	Frontal inferior
FS	Frontal superior
HbO	Oxyhemoglobin
HbR	Deoxyhemoglobin
HbT	Total hemoglobin
L2	Second language or foreign language (taken indistinctively in the dissertation)
LH	Left-hemisphere
LHBD	Left-hemisphere brain damaged
MIC	Micro-propositional
MAC	Macro-propositional
NIRS	Near infra-red spectroscopy
OI	Optical imaging
PET	Positron emission tomography
RH	Right hemisphere
RHBD	Right-hemisphere brain damaged
ROI	Regions of interest
SIT	Situational model
WM	Working memory
YE	Young English native speakers
YF	Young French native speakers

CHAPTER 2

REVIEW OF LITERATURE

This chapter presents the state of the art of the two main issues focused in the dissertation: discourse processing in aging and in bilingualism, starting with a discussion on discourse processing in general, to further relate it to the specific cases of bilingualism and aging. After this general discussion about discourse processing, including studies with healthy and brain damaged participants investigated under behavioral or imaging studies, the chapter then discusses the neurobiological representation of discourse processing in aging and presents approaches to explain the effects of aging in cognitive processes, including language, and more specifically, in discourse processing. Then, it presents fundamental issues regarding language processing by bilinguals, to focus on discourse comprehension by this population.

2.1 DISCOURSE PROCESSING AND ITS NEUROBIOLOGICAL REPRESENTATION: A GENERAL OVERVIEW

This chapter will focus on how the brain processes messages at the discourse level and on the role of each hemisphere in this process. Evidences will be brought from

behavioral and neuroimaging studies developed with brain-damaged and healthy participants.

Discourse comprehension and production is constructed by the establishment of the intrinsic relations between each and every component of the language system (phonological, semantic, syntactic and pragmatic elements), as well as with extra-textual information linked to our long-term memory (LTM), which is required to infer meaning and accommodate textual information in our memory. Along with intralinguistic and extralinguistic components, discourse processing may as well be affected by different aspects related to individual differences, such as those related to aging (Radvansky et al., 2001; Morrow et al., 1997), to individual abilities of approaching and comprehending a message (Tomitch, 2003; Dannemann, 1991; Gagné et al., 1993), or to varying levels of language proficiency, in the case of second language users (Urquhart & Weir, 1998; Zwaan & Brown, 1996).

2.1.1 The organization of the discourse level in the brain

According to van Dijk (1997) and Stemmer (1999), discourse has three main dimensions. It consolidates itself whenever there is language use, communication of beliefs (reflecting an intrinsic relation with cognition), and interaction in social situations. Therefore, discourse is intrinsically correlated to naturalistic language use and, as a consequence, it may take different forms depending on the functions it may serve. These different functions attained by discourse usage lead it to be organized in four different forms (Houg & Pierce, 1993; Ulatowska et al., 1990). First, discourse may

take a procedural form when it serves as a means of conveying the procedures involved in performing an activity. Also, it may be organized in an expository way whenever information on a single topic is conveyed by a single speaker. It has a conversational structure when one or more speakers exchange information with one or more listeners. Finally, it assumes a narrative organization when the message is formed by a description of events. The narrative form has been one of the most analyzed aspects in studies of discourse processing (both in production and in reception) so far, probably due to its well-defined structure of presentation and to its high frequency of occurrence in everyday life. The exposure to narratives initiates very early in infancy, since the first and the great majority of the texts addressed to children, and gradually produced by them, are narratives.

Whenever a message is conveyed, different structures come into play, in more or less explicit manners. In general, in ordinary interpersonal communication, part of the message is explicitly stated on a text basis, part has to be built or inferred by the receptor of the message (reader or listener) by the aid of textual traces that may help process it in a cohesive and coherent way, and/or yet, part of the information has to be drawn from extratextual information which resides in the interlocutor's world knowledge (Kintsch, 1998). Due to this complex interaction between explicit and non-explicit contents, linguistic and extra-textual information in discourse exchanges, the existence of a shared world knowledge and knowledge of schematic text typologies are crucial for successful communication. These types of knowledge become even more relevant when one considers the fact that several times in daily discourse the speaker/writer expects the

interlocutor to understand a message other than the one s/he explicitly states, as in the case of irony, as well as in several other situations of figurative language use.

The different components of a text have been presented by Frederiksen et al. (1990), van Dijk and Kintsch (1978) and Kintsch (1998) as being the micropropositional, the macropropositional and the situational levels. All the three levels are processed simultaneously and intra/interdependently. The micropropositional model is formed by the representation of detailed informative content, presented by each and every piece of information corresponding to the narrative represented as a proposition. Groups of micropropositions, linked due to the existence of common arguments, because of temporal, spatial, or causal relations, or of a common schema (Kintsch 1998, p. 225), are deleted and replaced by a common macroproposition, which will be formed according to the macrostructure of a narrative. Simultaneously, this new macrostructure links to other macrostructures, some probably already connected to long-term working memory (LTWM)[1]. According to Kintsch (1998), macrostructure generation of texts within a familiar domain is an automatic process that demands a certain amount of inference generation, of a type that reduces rather than adds some content to the text; in other words, macropropositions "do not have to be inferred by some special inference procedure but become available automatically in long-term working memory" (Kintsch, 1998, p. 177); that is, macropropositions do not have to be formed, when processing message within a familiar domain; rather, "the process of textbase construction simply makes them potentially available" (p. 177). Finally, the situational model is obtained by

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[1] Kintsch (1998, p. 217) defines "long-term memory" (LTM) as being "everything a person knows and remembers: episodic memory, semantic memory, as well as declarative and procedural knowledge", and "working memory" as being the active part of LTM responsible for retrieving and processing information.

the matching between the micro- and macropropositions and the semantic knowledge. The integration of micro- and macropropositions with semantic knowledge occurs by the implementation of integrative operations and schema[2] constructions, resulting from the combination of text-based and world knowledge information. The achievement of a coherent situational model, obtained through the interactive processing of both text-based and world-knowledge information, permits the storage of the content of the text (read or listened to) into memory (not in its individual and exact words, since our memory for pure text-based information is not long lasting (Radvansky et al, 2001) and text-based information is substituted by macropropositions), as already mentioned, but in its ideational structure, organized in coherent schemas that can be integrated into existing knowledge, expanded by the integration of new-incoming information, and retrieved whenever necessary.

In general, to build the situational level, some inferences need to be drawn by the reader / listener, who produces an array of possible inferences, based on world knowledge, to build the bridge between ideas that may not have been so explicitly linked in the text, in order to maintain text coherence and integration. A well-succeeded inference, chosen among all possible ones, can be coherently integrated into the internal representation of the text (Newman et al., 2004). This is the assumption of the Construction-Integration Model, proposed by Kintsch (1994). According to this model, the first step in drawing inferences is letting all possible inferences available, while the second step would be choosing the most coherent and related one(s) according to the

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[2] According to Rumelhart (1977) and Gagné et al. (1993), "schemas" are units of information which individuals attempt to create in order to assimilate incoming information and accommodate it in memory. These categorically organized memory structures may, thus, facilitate coding and recall.

precedent part of the text. Finally, the best match would be chosen and integrated into the existing representation of the text in the reader/listener's mind, allowing for new incoming pieces of textual information to be integrated.

The automaticity in macrostructure construction, its interconnectivity to LTM and the different cognitive demands required for processing textual and situational levels have led Kintsch (1998) to postulate the existence of mainly two different levels in discourse processing: textbases and situation models, rather than the differentiation between micro-, macropropositions and situation model (van Dijk & Kintsch, 1978, 1983).

The study of how discourse is processed in the brain represents a very recent field of research. Evidences found so far have indicated that this processing demands the participation of both cerebral hemispheres, as will be discussed below. Behavioral and imaging data, from healthy and brain-damaged individuals, have brought evidences to assume that the cerebral hemispheres differently cooperate for processing discourse, the topic to be discussed in the section that follows.

2.1.2 Hemispheric contribution to discourse processing: an overview

Much investigation is still needed in order to reach a full understanding of how the brain processes languages in general, and of how the hemispheres treat languages in particular and each of its components, with a special attention to the RH, whose functioning and roles in language processing have more recently started to be studied.

Beeman and Chiarello (1998) state that a cognitive neuroscience approach which seeks for this type of investigation has to include at least four goals:

1. Describing the processing patterns of each hemisphere

2. Describing the biological (macro- and microanatomical, chemical, physiological) asymmetries of brain areas involved in language

3. Using each level of information to guide/constrain search at the other levels

4. Eventually linking cognitive processing of both hemispheres to their biological characteristics.

(Beeman & Chiarello, 1998, p. 377)

Initially, it has been believed that language processing would be almost exclusively assigned to the LH. However, mainly since the 1990s, research has pointed to a prominent participation of the RH as well. It is at the discourse level that the RH seems to be especially important. Its linguistic potential is linked to determined capacities, and it may assume more linguistic functions when the LH cortex is removed between one and five months after birth (Dennis & Whitaker, 1976, as cited in Paradis, 2004, p. 172). Finally, it is important to state that counter-lateral activation in the RH has frequently been registered in neuroimaging studies of language processing, in the various language components, in comprehension and production, in oral and written modes of presentation.

The cognitive demands underlying discourse processing have been investigated mainly through behavioral studies, and only more recently the availability of neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), has allowed researchers to investigate the neurophysiologic bases underlying this processing. Imaging studies have postulated the existence of specialized areas in the brain responsible for certain linguistic processes, but also to the fact that different linguistic processes may co-occur in the same cerebral site (Keller et al., 2001). Regarding discourse processing, research has pointed to a relevant participation of the RH in comprehension and production at the text level (Myers, 1999; Joanette & Goulet, 1990), accompanied by an important supportive role attributed to the left hemisphere (LH) (Tomitch et al, submitted; Tomitch et al., 2004; Beeman et al., 2000). Bilateral activations observed in these and other studies indicate that the construction of a coherent discourse representation requires the participation of different regions within both hemispheres, which need to share and integrate information.

Activation of RH areas has been reported to be observable during tasks requiring metaphorical comprehension, when there is an activation of the RH homologous to Broca's and Wernicke's areas in non-brain-damaged participants (Huber, 1990); similarly, activation in the right frontal and temporal regions has been observed in studies that verified the sites where judgments about the moral of a fable take place, as compared to judgments about the literal meaning of a story (Nichelli et al., 1995).

Recently, different studies have aimed to verify semantic processing, by both normal and impaired RH subjects, mainly at the discourse level, some of them also investigating sentence comprehension and lexical access (Tomitch et al., submitted;

Tomitch et al, 2004; Newman et al., 2004; Waldie, 2004; Waldie & Mosley, 2000; St. George et al., 1999; Federmeier & Kutas, 1999; Stemmer & Joanette, 1998; Beeman & Chiarello, 1998; Dehaene et al., 1997; Hough, 1990; Joanette & Goulet, 1990; Joanette and Brownell, 1990; Kaplan et al., 1990; Molloy et al., 1990, among others).

According to Stemmer and Joanette (1998), the different accounts for detecting the presence of discourse impairments proposed in the literature can be summarized under five headings:

1 Impairment at the level of narrative script, schema, or frame construction or interpretation

2 Impairment at the level of inferential processing

3 Impairment in integrating information or conceptualizing the unit as a whole

4 Impairment at the level of processes that construct new conceptual models

5 An impaired theory of mind model

(Stemmer & Joanette, 1998, p. 331)

Congruent findings reported in the literature have led researchers to assume that the RH is responsible for semantic integrative processes at the level of discourse, while the LH seems to be responsible for lexical integration at more basic structural levels; that is, LH language areas would struggle mainly with local coherence (between and within sentences), while RH brain areas should be responsible for global coherence, at the macrostructure of the verbal message (Gernsbacher & Kaschak, 2003).

At the word level, hemispheric functions have shown to be differently assigned, although in a complementary way (Waldie & Mosley, 2000). When accessing the lexical meaning of a word, the LH has been pointed to be responsible for searching a *focal*, smaller, semantic field, and activation of the lexicon may be limited to the target meaning and its most closely linked associates, a process done quickly and automatically for everyday activities. On the other hand, the RH may be responsible for *coarse* coding, that is, each word may be associated with a large, diffuse, semantic field, in which several concepts may be activated and maintained available for use. As stated by Molloy et al. (1990), the RH is considered to be the memory buffer for alternative meanings. Thus, inability to retain alternative meanings (both literal and figurative) would crucially limit the capacity to evaluate ambiguous utterances or to revise assumptions.

To establish a parallel between the two hemispheres in relation to the activation of meanings of words, we can mention Federmeier and Kutas's (1999) review. These authors pose that the RH is integrative, that is, it establishes a direct comparison between the features of items in context and those of the current word; it activates a broader range of words; it activates semantic information more slowly and maintains it for longer; it takes advantage of a greater use of associative information from the sentence. As for the LH, they pose that it is predictive, in the sense that it compares new information with predicted elements; it activates items likely to be encountered; it narrows attention to highly related words; it is sensitive to message level, contextual constraints; it has difficulty in revising information and reinterpreting it; it is faster, more selective and used in everyday language.

Much research is still needed until we reach a deeper understanding of the inter- and intra-hemispheric dynamics in language processing and, specially, in discourse processing. However, some important findings have already been found in imaging and behavioral studies investigating brain-damaged and healthy participants' text comprehension and production. Data brought by some of these studies will be discussed below.

2.1.2.1 *Evidence from neuroimaging and behavioral studies with brain-damaged participants*

Studies investigating discourse processing by right-hemisphere brain damaged (RHBD) participants have found common problems among this population at the discourse level. RHBD patients exhibit qualitatively different verbal communication deficits as compared to left-hemisphere brain damaged ones (LHBD), but equally or even more disabling. In his review, Paradis (2004, p. 15-17) mentions that the RH deficits described so far are of a pragmatic nature, basically comprising difficulty with comprehension and/or production of affective prosody, indirect speech acts, metaphors, and connotative meanings, as well as other deficits at the level of discourse, such as deriving the gist of a story or the moral of a tale, and in general, problems of cohesion. According to the literature, RHBD participants have revealed difficulties in the following aspects: 1) discourse organization, cohesion and logical coherence (Marini et al., 2005; Myers, 1999; Brownell & Martino, 1998; Joanette & Brownell, 1990; Hough,

1990; Molloy et al., 1990; Joanette et al., 1990); 2) interpretation of theory of mind[3] and of the speaker's mood (Brownell et al., 1992; Kaplan et al., 1990), and related deficits such as an impaired ability to adopt the mental set of another person (Siegal et al., 1996), a reduced sensitivity to effect of conversational violations (Rehak et al., 1992), and a difficulty in perceiving the emotional state of a story character (Bloom et al., 1992); 3) use of contextual information to interpret discourse (Brownell, 1988); 4) inferring the gist or main ideas, and getting the point (Hough, 1990); 5) story or narrative processing (Joanette & Goulet, 1990; Joanette et al., 1986); 6) prediction (inference generation) and revision (revision of initial inferences) (St. George et al., 1999; Molloy et al., 1990); 7) comprehension of indirect requests and verbal irony; 8) comprehension of jokes, cartoons and humor in general (Bihrle et al., 1986); 9) interpretation of figurative meaning and metaphorical idioms (Huber, 1990), figures of speech, idiomatic expressions and connotative meaning; 10) reduction in levels of informative content (Marini et al., 2005; Urayse et al., 1991), by the use of simplified discourse (reduced production of qualitatively and quantitatively complex propositions) (St. George et al., 1999); 11) excessive output: digressions, tangentiality (Myers, 1996, 1984; Hough, 1990); 12) activation of ambiguous word meanings based on meaning frequency, not on context (Grindrod & Baum, 2005); 13) difficulty in maintaining the theme of a conversation (St. George et al., 1999); 14) difficulty in drawing inferences or in revising them when new information comes up (St. George et al., 1999).

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[3]A "Theory of Mind" (often abbreviated in TOM) is a specific cognitive ability to understand others as intentional agents, that is, to interpret their minds in terms of theoretical concepts of intentional states such as *beliefs* and *desires* (Kaplan et al, 1990).

These are some of the most common disturbances noticed in RHBD participants; however, it is important to observe that, although not all of them have all or some of these problems, if they do, their problems will probably fit into one or more of the categories described above (Stemmer & Joanette, 1998).

From the results of the studies above, the importance of an intact RH for discourse computation seems to be evident. It is responsible for integrating information in a coherent and holistic manner, as signaled by Hough (1990), whose study reflected RHBD participants' difficulty in getting the main idea of short narratives when information is presented in a noncanonical form, that is, when theme presentation is delayed. She concluded that RHBD adult patients seemed to be unable to apply the use of the macrostructure as an organizer in apprehending a paragraph, which resulted in retention of isolated pieces of paragraph data rather than in an integration of this information to deduce the meaning of the narrative. This corroborates Joanette and Goulet's (1990, p. 149) assumption that the occurrence of a RH lesion affects more the content than the form of narrative discourse.

Right-hemisphere-based skills, mainly ability to make inferences from context and general knowledge, are used by agrammatic patients, children, genetic dysphasics and L2 learners in order to get the meaning from the speaker's intention without depending on the process of decoding the syntactic structure. Molloy et al. (1990) and Huber et al.'s (1990) studies have postulated that an impaired performance of RHBD patients is reflected on a reduction in their capacity to use prior knowledge to approach a text in a top-down manner.

Some behavioral studies have also investigated RHBD participants' capacity of understanding discourse.

Brady and colleagues (2006) assessed RHBD participants' discursive abilities at 1 and 6 months post-onset of the stroke. They evaluated their abilities in seven discourse samples (three conversational, three procedural and a picture description). Very few significant differences in performance were found over time in the abilities measured.

Titone and colleagues (2001) tested the hypotheses that "impaired discourse processing following RH damage is mediated by task difficulty and is associated with deficits in discourse encoding". Spoken passages were presented to RHBD and non-brain damaged participants in normal or accelerated speech rates (to increase task difficulty), and subsequent recall was analyzed. RHBD showed an overall deficit in recalling and failed in recall major idea units better than minor idea units for passages in accelerated speech rates. They concluded that extracting the gist of a story under difficult listening conditions is especially difficult for RHBD individuals.

The next section discusses data brought by neuroimaging and behavioral studies on discourse processing by healthy (non-brain-damaged) participants.

2.1.2.2 *Evidence from neuro-imaging and behavioral studies with non-brain-damaged participants*

Imaging tools have mainly aided studies of language production and comprehension at the word and the sentence levels, being their application for the investigation of discourse processing very recent (Scherer et al., 2006a, Tomitch et al.,

2004; Robertson et al., 2000; St. George et al., 1999; Nichelli et al., 1995). The increase in discourse studies implemented with imaging techniques may provide support for a deeper understanding of the neurocognitive activity related to higher level language processes, engendering into the interhemispheric dynamics that take place when an individual copes with a message at the discourse level in its different components - text-based (micro- and macropropositional levels) and situational levels.

Neuroimaging studies at the discourse level have focused almost in their totality on discourse comprehension, while productive processes are still waiting for investigation. Discourse comprehension has been studied basically through passive story listening. Table 2 reports some of the investigations on discourse comprehension by healthy participants, with the aid of neuroimaging tools, mainly PET and fMRI, and specifies the type of task used and the brain sites activated.

According to the studies presented in Table 2, the main cerebral sites activated during discourse comprehension and production are: middle temporal regions (mainly in the RH), an area responsible for integrative processes for global coherence (St. George et al., 1999); right and left inferior frontal lobes, for story processing within a coherent representation; left temporal region, mainly the hippocampus, responsible for maintaining the coherence of incoming information, thus related to memory processes; the precuneous, linked to other cortical regions and implicated in memory processes. Frontal areas in the RH have been noticed to be active in tasks that demanded the construction of story representations, but not during passive story listening, as seen from the table below and also stated in the review presented by Gernsbacher and Kaschak, (2003).

Table 2: Review of some imaging studies at the discourse level – oral production and reading comprehension

Researcher(s) / type of imaging	Type of discourse processing	Brain sites
Tomitch et al., 2004 - fMRI	Mapping the main idea of a short text (presented at the beginning or at the end of a written paragraph)	Bilateral activation (temporal, inferior frontal, pre-frontal dorsolateral cortex)
Braun et al., 2001 - PET	Narrative oral production in English and in American sign language (autobiography): both have in common = conceptualization and lexical access; difference between them = mode of expression	- RH classical areas = also activated for sign language - widespread activation = beyond classical language areas, included extrasylvian regions in both RH and LH - posterior perisylvian and basal temporal regions = self-generated production of language - discourse generation: progresses from early stages of bilateral lexical access to left-lateralized articulatory-motor encoding
Caplan et al., 2000 - fMRI	Logic and topic maintenance in conversation (oral comprehension)	a) judging discourse coherence (logic) = left fronto-temporal and anterior cingulate network b) topic maintenance (organization and flow of ideas) = right fronto-temporal and cerebellar network
Robertson et al., 2000 - fMRI	a)Reading sentences connected or non-connected to a discourse b)Narrative processing	a) Connected sentences= RH middle and superior frontal b) More distributed in RH: precuneous, cuneous, posterior cingulate, parieto-temporo-occipital (bilaterally); frontal poles; stretch of cortex from right superior temporal sulcus to right temporal pole (=picture stories)

St. George et al., 1999 - fMRI	Integrative processes for global coherence in reading (titled / untitled short stories)	Bilateral: inferior frontal & temporal (+ RH = untitled)
Tzourio et al., 1998 - fMRI	Passive story listening	Bilateral temporal poles; left middle temporal gyrus (no RH frontal regions)
Binder, 1997 - fMRI	Receptive language processing in listening to stories	L frontal lobe= language executive: coordinates sensory and semantic processes in posterior areas and accommodates shifts in goals / strategies
Nichelli et al., 1995 - PET	Thematic interpretation of a written text / appreciation of the moral of a story	RH inferior frontal; temporal lobes (right middle temporal gyrus)
Fletcher et al., 1995 - PET	Processing of two different types of written stories (theory of mind, physical events) x unrelated sentences	Bilateral temporal poles, left superior temporal gyrus, posterior cingulate cortex (=connected to prefrontal and middle temporal gyrus = encode episodic memory); L middle- frontal gyrus = theory of mind)
Mazoyer et al., 1993 - fMRI	Processing of meaningful stories (passive listening)	Left middle temporal gyrus; left superior prefrontal; L/R temporal poles (L= memory for linguistic content/ R= encoding and storage of pragmatic, prosodic and other discursive aspects); no RH frontal

Finally, an increase in activation in determined areas and a more diffuse activation may sometimes be related to an increase in task difficulty, as well as to the type of task the participants developed, for instance, whether written or aural, whether passive listening versus judgment tasks or covert text structuring activities.

An analysis of the studies presented in the table above and of others on healthy participants' discourse processing corroborates the determinant participation of the RH in this task. According to St. George et al. (1999) and others, RHBD participants recognize individual words and comprehend sentences, but have trouble connecting and integrating semantically and/or temporally distant concepts. St. George et al. mention that "an intact RH seems to be especially important for higher level integrative processes that lead to functional coherence in discourse" (p. 1318). In their study they aimed to compare hemispheric activation in the presence and absence of a title presenting a paragraph. They observed an increased blood flow in both hemispheres as individuals read short paragraphs word by word for comprehension, but a prominent activation in the right inferior temporal sulcus and in the right middle temporal sulcus occurred for the untitled condition, a task that demands greater recruitment of areas responsible for comprehension at the discourse level, by mapping information for textual representation. Moreover, activation was more diffuse in the right than in the left hemisphere. A similar result was elicited by Newman et al.'s literature review (2004), which stated that research using fMRI technique has shown a greater activation of the RH in processing paragraphs presented without a title.

Finally, the fMRI study developed by Tomitch et al. (submitted) with non-brain-damaged subjects has corroborated the relevant role of the RH at the discourse level,

indicating its capacity to detect the main idea, independently of its position in the paragraph: first or last.

A behavioral study developed by Beeman and colleagues (2000) has analyzed discourse processing, also pointing to a relevant participation of the RH in this task. They investigated the relationship between semantic coarse coding and the construction of inferences. According to Beeman (1993), (and as already explained in section 2.1.2), semantic processing may involve coarse and/or fine coding. Fine coding is the retrieval of the closest meaning of a word whenever it is read or listened to; this activation is more rapid and automatic, essential for ordinary language use, and seems to be carried out mainly by the LH. Yet coarse coding, an attribution mainly attained to the RH, refers to the retrieval of a broader semantic net associated to a word, an important tool for the comprehension of non-literal, connotative and figurative language. Empirical evidence brought by the study of Beeman and colleagues (2000) has shown that the access of coarse meaning in the RH facilitates the processes of drawing predictive and coherence inferences during story comprehension, fundamental processes for the construction of a situational model, and consequently, for the achievement of the global coherence of a text. By orally presenting stories to the left visual field (lvf) - RH or to the right visual field (rvf) - LH of healthy young participants, the authors tested participants' ability in drawing coherence and predictive inferences. Participants showed priming effects for predictive inferences for target words presented to the lvf-RH and priming for coherence inferences only for target words presented to the rvf-LH. This suggests that predictive inferences are more likely activated in the RH and that coherence inferences are completed in the LH.

The exact participation of each hemisphere in discourse processing is still not fully understood, nor are the factors that influence and demand this joint participation, some of these possibly being related to aspects such as task typology and demands, as well as to individual strategy choices to cope with the tasks. Besides, as already mentioned, individual differences, such as those generated by aging, may also contribute for different hemispheric attributions in the processing of discourse and of other language components. This will be the topic of the next section.

2.2 THE REPRESENTATION OF DISCOURSE PROCESSING IN AGING

Some individual characteristics may interfere with the way we process messages at the discourse level. One of these factors is related to aging and the cognitive, motor and sensory changes that may accompany it.

Aging is becoming an important research field in the 21st century. In most developed countries, average life expectancy has increased from about 45 years in 1900 to about 75 years in 1990 (Kannisto, 1994, in Li & Dinse, 2002). Therefore, with the rapid growth of worldwide population, as stated by Li and Dinse (2002), there is an urgency in better understanding the mechanisms and processes influencing cognitive and sensorimotor aging, for "reducing decline or enhancing individual and environmental compensatory functions" (p. 729). Thus, the study of language processing and, more specifically, of discourse processing by elderly populations may contribute to diagnose,

prevent, minimize and/or treat discourse production and comprehension problems which may be generated by aging.

The main neuropsychological aspects and other factors that may emerge and interfere in discourse processing by elderly people, the features of discourse processing in aging, and the theories that aim to explain this processing are the focus of this section.

2.2.1 Neuropsychological changes and other factors influencing discourse processing in aging

Discourse comprehension by the elderly may be affected by concomitant variables, such as changes in attention and executive functions (Stemmer, 1999; Eviatar, 1998; Stemmer et al., 1994), changes in memory and/or working memory capacity (Linden & Poncelet, 1998), or in inhibitory and excitatory mechanisms (Beeman, 1998). Some changes in the nervous system may also play a role: neurophysiological changes such as a reduction in size and number of neurons, a diminished efficiency in synaptic contacts, and neurochemical changes through a reduction in the concentration of neurotransmitters such as dopamine (Raz, 2000). Also, disturbances in neuroanatomic structures such as the pre-frontal cortex (Grady et al., 1998) and a reduction in the volume of the brain both in the gray and in the white matter (Raz, 2000) have been registered. Structural changes in the brain start around the age of 30, but the losses are not uniform: they seem to be higher in prefrontal regions, smaller for parietal and temporal areas and small and often non-significant for sensory and motor cortices (Raz, 2000). Declines have also been reported in the white matter, again, more pronouncedly

in frontal regions (Head et al., 2004). Studies have shown that changes in brain structure can affect both cognitive performance (leading to lower performance in tasks dependent on those areas with volume reduction) and patterns of cortical recruitment (older adults frequently recruit other brain areas in addition to those recruited by younger adults) (for a review of studies see Kramer et al., 2006).

According to Grady (2006), the most evident declines generated by aging can be observed in episodic memory, attention and aspects of emotional perception, while no changes or even improvements have been registered in semantic memory and in aspects of social cognition, such as in the application of the theory of mind. This author postulates the existence of a different functional connectivity with age (corroborating the idea of the occurrence of changes in the patterns of cortical recruitment, mentioned above), that is, the engagement of different brain networks by elderly people as compared to younger ones, which may indicate the occurrence of a compensation or of a different strategy choice to cope with a task. She has observed that the default mode (that is, the brain areas detected by fMRI that remain active when someone is *not* doing a task and thinking, for instance, about errands) continues to be more active in older adults, which may explain their higher tendency to distraction, as the default mode is supposed to be de-activated while one executes a task. Recent research has aimed to investigate whether the extra recruitment of brain areas represents a form of compensation or a marker of cortical decline (that is, "a failure to recruit specialized neural processors") (Kramer et al., 2006, p. 67). This issue will be developed in the section on the different theories to explain cognitive (including language) processing in aging.

Along with the changes mentioned above, other aspects related to experimental conditions and to individual differences within an aged group of research participants may play a role in the findings brought by the different studies presented in the literature. Following, important aspects interfering in discourse processing in aging, namely attention and executive functions, working memory capacity, and individual differences within the aged group, as well as the influence of experimental conditions in discourse tasks, will be discussed.

a) *Changes in attention and executive functions*

A decline in the performance of elderly populations in language activities can be linked to changes in attention and executive functions. These changes may lead to a general slowed speed in the treatment of information, difficulties in telling important from irrelevant information, as well as difficulties in treating two types of information at the same time (Ska & Joanette, 2006).

Changes in inhibitory and excitatory mechanisms, leading to a reduced inhibitory control and a reduced resistance to interferences when performing tasks in aging, would interfere with higher level processing (Hasher & Zacks, 1988), since older adults may have a greater difficulty in inhibiting irrelevant information, which would cause an overcharge on WM capacity.

b) *Changes in working memory capacity*

Three particular aspects of memory have been investigated in aging: age-related dissociations between declarative and non-declarative memory, the role of the left and right prefrontal areas in recollection and familiarity phenomena, and the role of the prefrontal cortex in WM function (Kramer et al, 2006, p. 73).

Our memory system can be decomposed in different subsystems: episodic, semantic, procedural and working memory (Ska & Joanette, 2006), each one differently affected by aging. For instance, it has been shown that semantic memory, including vocabulary acquisition, continues to improve with age (Verhaeghen, 2003).

WM is relevant in language processing (Tomitch et al, 2004, Rodrigues, 2001, Just & Carpenter, 1992, among others) and seems to be affected by aging. For instance, WM is responsible for determining a slowed and less accurate recall of propositions in aging when there are higher structural syntactic demands on the sentence, but not for simpler syntactic structures (Stine & Hindman, 1994); however, some researchers assume that these differences may not be language specific (Vos et al., 2001; Kluender & Kutas, 1993; King & Just, 1991), but rather a result of changes frequently associated to aging.

A reduced WM capacity in aging would be more prominently detectable in higher order language processes, such as complex sentences and discourse tasks, in which predictive processes would become less likely or less efficient, rather than at lower levels, such as at the processing of lexical associative relationships (Federmeier et al, 2003). Evidence for a reduced capacity detectable in higher order language processes has also been found by Tompkins and colleagues (1994), who developed a study to investigate the relation between WM capacity and comprehension of passages that

demanded revision of an initial interpretation. They were especially interested in analyzing the role of the RH in this process. Their RHBD aged participants showed a significant reduction in discourse comprehension when the task requirements where increased, not observed in their normally aging participants, who were not expected to have problems with the task. The authors based the discussion of their results on the theory proposed by Just and Carpenter (1992), the theory of capacity-constrained comprehension. They suggest that "WM influences comprehension only as processing demands approach or exceed the limits of capacity" (p. 122), which, in RHBD elderly individuals is linked to their reduced WM total capacity and to a faulty resource allocation. Studies such as these developed by Federmeyer and Tompkins corroborate the assumption made by Rodrigues (2004), who points to the fact that language impairments, more specifically in Alzheimer disease, can not be attributed nor assessed only considering deficits in semantic processing, such as in word retrieval. He states that language impairments may as well occur in higher order language levels and should be assessed in order to more completely diagnose language deficits in dementia.

Regarding sites of brain activation, Cabeza and co-workers (2002, in an fMRI study) and Li and colleagues (2004, a PET study) postulate the occurrence of an increased or more diffuse frontal activation in older as compared to younger adults in tasks requiring effortful retrieval and/or source judgments. Moreover, studies have shown elderly participants' recruitment of more areas, often bilaterally, to perform dual tasks or tasks imposing a heavy load on WM capacity (Smith et al., 2001; Reuter-Lorentz et al., 2000).

Johnson (2003) developed a meta-analytic review of research that aimed to assess younger and older adults' performance in learning and remembering from texts, by testing verbatim and substantive free recall, cued recall, recognition, and true-false verification. The differences obtained in the comparison between younger and older adults varied according to the types of learners, text typology, learning instructions, procedures and types of scorings adopted. Some of the results found were that age related differences were higher for shorter texts than for longer ones, and regarding comprehension and recall versus text typology, the most difficult type of texts were newspaper articles, followed by narratives, with expository texts being the easiest for aged people. Descriptive texts and narratives showed similar patterns of comprehension, and their comprehension was easier than the study of lists of unrelated sentences.

Longitudinal studies on memory capacity for recall of narratives have shown no declines in young-old adults, but in old-old adults (older than 70) (MacDonald et al., 2003).

Although more conclusive studies still need to be developed on the effect of aging in working memory, evidence already found seem to indicate a positive correlation between these two factors.

c) *Influence of individual differences within the aged population*

Regarding individual differences, age-related differences in reading comprehension and recall seem to be larger when comparing young adults to old-old adults (70 and older); however, when older participants have an advantage in vocabulary

or intelligence over younger ones, differences related to age are smaller, as stated by Meyer and Pollard (2006). Thus, an advantage in vocabulary or in intelligence is able to reduce possible deficits in reading comprehension and recall in the aged population.

Another important issue related to individual differences in aging is brought by the concept of cognitive resources available while a person gets older. According to Baltes (1997), there are two fundamental types of cognitive resources: those brought by birth and on which one can count on (from *nature)*, and those developed over lifetime experience, through learning and practice (from *nurture*). The concept of cognitive resources is directly related to the concept of brain plasticity, in the sense that the amount of resources available, brought both by birth and by experience, may be accommodated by brain structures and functioning. As stated by Ska and Joanette (2006), certain individual characteristics may modulate cognitive resources. Among them, the authors include cognitive styles (whether analytic or global), the type and level of education, personality traces, health conditions, the type of knowledge or experience (determined by studies or professional experience), and life style.

Individual differences in aging are related to the concept of "successful aging", "well aging", or still "healthy aging", and may be determined by individuals' different levels of maintenance of physical, mental and social autonomy (Van Faber et al., 2001), which may affect elderly people's performance. The concept of "successful aging" can be defined according to different facets: cultural (Western x other cultures), of perspective (the researcher's or the elderly person's one), and of content (biomedical or holistic) (for a detailed explanation, see Gangbè & Ducharme, 2006). Gangbè and Ducharme (2006) state that the models which try to explain the "successful aging"

concept can be divided into two broad groups: the uni-dimensional models, which base their assumptions on a single scientific discipline – the Biologic, the Cognitive and the Psychosocial Models, and the multi-criteria models, which integrate different scientific perspectives – the Rowe and Khan Tri-dimensional Model, the Selection-Optimization-Compensation Model of Baltes and Baltes and the Riley and Riley's Model of Structural Lag (p. 298-299). According to the authors, psychosocial factors are the most frequent determinants focused by the models, which emphasize the possibility of mobilizing, reinforcing and teaching some of these factors, mainly social and personal resources. They suggest that the integration of the various models could lead researchers to aid the promotion of more effective "successful aging" programs in the future.

d) Influence of experimental conditions linked to reading tasks

As for the role of experimental conditions, many aspects have been reported to influence the different, and sometimes incongruent, data presented in the literature, as stated by Meyer and Pollard (2006). The authors state that age effects seem to be reduced when participants read longer texts in comparison to short passages, probably because longer texts are more similar to those they are used to read in a daily basis and from which they try to get the gist. Also, the differences seem to be reduced for the written, or written and aural mode of presentation than for the aural presentation. Another aspect related to experimental designs refers to the time assigned for task resolution. Self-paced reading tasks reflect reduced number of deficits as compared to experimenter-imposed time limits. Finally, the authors report that manual reaction- times

responses elicit greater age effects, as compared to task requiring *yes* or *no* judgments or selecting a response, whereas no differences have been found regarding written versus oral mode of response.

Regarding task complexity, age-related differences seem to be more evident in lab situations, but not in everyday problem solving or job-related tasks, as attested by recent studies (Finucane et al., 2005; Taylor et al., 2005). Therefore, it is important to try to maintain the experimental environment as natural as possible, in order to reduce its interference in the data obtained.

Another important issue to be considered is the complexity of the reading process itself, regardless of the reader's age. As stated by Meyer and Pollard (2006, p. 237), reading has a lot of variables, such as text length, gender, readability, presentation method and purpose, which can each one in turn determine the way we approach a text. For instance, both young and elderly readers have different purposes when reading a text, and to follow them, they may use different strategies, such as changing the reading pace or re-reading certain parts or the whole text, which is not always the case when they are invited to read in a lab condition, under unnatural conditions, sometimes approaching unfamiliar texts, in unfamiliar conditions, and being asked to do unfamiliar reading tasks. Therefore, as already mentioned, the experimental demands and environment should be as natural as possible to minimize their effects in the results to be found.

Now that the main neuropsychological changes brought by aging and other concurrent factors to be analyzed in studies of language processing in aging, such as the influence of individual differences and of experimental conditions, have been presented,

the effect of this frame will be discussed in terms of its influence in discourse processing by elderly individuals.

2.2.2 Discourse processing in aging

Discourse studies with healthy and brain-damaged populations have been developed with imaging methods, as already presented in this dissertation; however, the population investigated has mainly been formed by young adults (or children, studies not covered in this dissertation), while the comparison between their performance to the one of an elderly population has very recently and scarcely been focused with the aid of imaging techniques (Scherer et al., 2006b).

Studies on language processing in aging have concentrated more on text-based than on situation-based representations (Stine et al., 1996). As stated by Morrow et al (1997), these studies have shown an age effect when there is an overload on cognitive resources, such as in the case of complex syntax, high information density or distance between anaphors and their referents in the text (for the specific studies, see Morrow et al., 1997, p. 73).

Some behavioral studies have aimed to compare discourse processing by younger adults (average age of 20 to 35) with discourse processing by older adults (average age of 60 to 75) (Hamm & Hasher, 1992; Stine-Morrow et al., 1996; Morrow et al., 1997; Soederberg Miller & Stine-Morrow, 1998; Radvansky, 1999; Radvansky et al., 2001; Smiler et al., 2003). Their findings concern mainly specificities in memory capacity, discourse comprehension in general and forms of approaching text-based and situational

levels of a text. This research has postulated that, while younger adults' memory seems to be rooted in the text, older adults' memory seems to be rooted in its interpretation. This explains the assumption, drawn from this literature, that younger adults have better memory for surface-form and propositional levels, while older ones have poorer memory for text-based propositions. As a consequence, there is evidence to assume the existence of a greater ability of younger adults to achieve higher levels of recall and comprehension at the micro-propositional level.

Regarding comprehension, although more conclusive evidence is needed, older adults seem to achieve the same (or sometimes higher) patterns of comprehension at global levels (situational model and macro-propositional level) than younger adults. One of the causes for this similarity (or, sometimes, advantage) may be a higher reliance of older adults on schema-based knowledge over situation specific knowledge (Soederberg Miller & Stine-Morrow, 1998), a greater reliance on on-line contextual facilitation (Stine-Morrow et al., 1996) or a wider activation and maintenance of possible inferences (Hamm & Hasher, 1992). However, a disadvantage that has been reported in older adults' discourse comprehension is their difficulty in organizing propositions according to their informational importance (Radvansky, 1999), which may in some cases harm and slow the comprehension process.

Some of the similarities found between older and younger adults' performance in discourse processing by behavioral studies are a rapid forgetting of text-based information, a similar capacity for updating models with new information, the use of similar types of situational models and a similar reading time in the majority of the tasks (Radvansky et al, 2001), although this is not a consensus among researchers, since some

studies, such as those developed by Stine-Morrow and colleagues, have reported an overall slowing in aging, in word, sentence and discourse processing.

2.2.3 Different theories to explain language processing in aging

The effects of aging on attentional and executive functions and on working memory in language processing lead to the postulation of different theories on language capacity in elderly individuals. Federmeier et al. (2003) present two accounts: one that assumes the occurrence of a generalized slowing in language processing, due to global neurobiological changes, and another that postulates the existence of a reduction on specific cognitive processing resources, such as the ones mentioned above. Thornton and Light (2006) classify the latest approaches that aim to explain age-related change and stability in cognition in five groups: cognitive slowing, "problems in working memory that affect storage and manipulation of information" (p.262), weakened inhibitory processes that could inhibit the activation of irrelevant information to the task to be solved, weakened connections among memory representations which reduce the transmission of excitation (the transmission deficit), and , finally, the emergence of sensory deficits. So far research has found evidence to corroborate all theories; therefore, further investigation is needed for a better understanding of the underlying basis for age-related differences in language processing in its different levels.

As stated by Thornton and Light (2006), current approaches in cognitive changes in aging have investigated the relation between sensory, phonological, orthographic, lexical, syntactic and semantic processing in relation to top-down or bottom-up

approaches, and have revealed a tendency for conceptually driven (top-down) processing as the preferred approach in aging. Moreover, the authors mention that latest research has also analyzed the occurrence of redefined goals, increases in expertise and application of compensatory strategies as factors to play a role in language and cognitive functioning in aging.

Based on assumptions which try to explain age related differences in brain function and cognition, different models have emerged: the Compensation Related Utilization of Neural Circuits (CRUNCH), by Reuter-Lorenz and Mikels (2005), the Cognitive Reserve (CR) hypothesis (Stern et al., 2003 and others), and the Hemispheric Asymmetry Reduction in Old Adults (HAROLD) model, by Cabeza (2002).

The CRUNCH model suggests the occurrence of an additional neural circuitry to cope with a declining neural efficiency. The authors state that compensation can happen in several manners, such as by the bilateral recruitment of homologous brain regions or by the recruitment of different brain regions for older and younger adults. As the model assumes that older adults will reach their resource limits sooner, it predicts: "(1) poorer performance for older than for younger adults on more complex tasks and (2) under-recruitment for old relative to younger adults as tasks become more difficult. Older adults should show a smaller change than younger adults in PET or fMRI activation as tasks become more difficult" (Kramer et al., 2006, p. 68). As stated by Kramer et al. (2006), this model needs further validation with different tasks and populations to determine its generality.

The CR (Cognitive Reserve) hypothesis bases its assumptions on the ability of older adults to cope with advancing brain pathologies through either a set of acquired

skills or inherent abilities. It relates to the level of education, IQ, occupational status, and/or other lifestyle factors (Stern et al., 2003). These variables may account for different degrees of brain pathologies among aged people, that is, the individual differences in terms of the number of years of formal education, for example, may explain why the degree of brain pathology does not always match with expected cognitive problems among elderly individuals. Research testing this model has shown changes in brain regions activation as a function of task difficulty, suggesting that different neural networks subserve difficulty-based compensation in older as compared to younger adults.

The third model aiming to explain the underlying brain circuitry for cognition and performance in aging, the Hemispheric Asymmetry Reduction in Old Adults (HAROLD) Model, posits that brain activity seems to be less lateralized in older adults than in younger ones (Cabeza, 2002). This framework will be explained in more details in the next section, since it will be applied to data analyses in the study here presented.

2.2.3.1 The Hemispheric Asymmetry Reduction in Old Adults (HAROLD) Model

A growing concern has been attributed to the role of each cerebral hemisphere in the processing of language components in aging, and a combination of imaging and behavioral studies have gradually been designed to investigate this issue (Ansaldo et al., 2005).

The assumption of a hemispheric asymmetry reduction in high-performance older adults when computing cognitive tasks is supported by functional neuroimaging

investigations and studies on episodic and semantic memory, working memory capacity, perception and inhibitory control (Cabeza, 2002; Cabeza et al., 2004). For instance, as stated by Kramer et al. (2006, p. 67), studies of episodic encoding, episodic retrieval, working memory and face matching have shown bilateral activation for older adults as compared to a more right or left lateralized functioning in younger adults. These authors mention a study by Reuter-Lorenz et al. (2000), in which data were recorder while older and younger adults solved a verbal and spatial working memory task. In the frontal lobes, for younger adults, activation was more left lateralized for verbal and right lateralized for spatial working memory, while older adults showed a more bilateral activation for both types of memory tasks.

Moreover, some studies have argued that older adults who perform better on a task have shown bilateral activation of homologous areas, whereas those who perform more poorly have shown unilateral activation (Cabeza, 2002, among others). However, these results have not been corroborated by other studies, which found no relationship between laterality and performance, or revealed unilateral prefrontal activation for better-performing and bilateral one for poorer-performing older adults (for a review, see Kramer et al., 2006).

To sum up, specifically in relation to the aging memory, the literature seems to suggest "a general compensatory role for the temporoparietal and prefrontal regions across different memory tasks for older adults" (Kremer et al. 2006, p. 67).

According to Dolcos et al. (2002), there are two models which account for hemispheric asymmetry in aging: the right-aging model, which postulates that the RH shows higher age-related decline than the LH, and the HAROLD Model, which proposes

that "frontal activity during cognitive performance tends to be less lateralized in older than in younger adults" (p. 819). A literature review of PET and fMRI studies on cognitive tasks performance in aging developed by Cabeza (2002) brings evidence to postulate the existence of an average higher activation in older adults' RH in comparison to younger adults' RH activation. According to the author, this reduced asymmetry may be a reflex of compensatory mechanisms, to cope with a possible neurocognitive decline, or of a de-differentiation process, an evidence of a possible difficulty in recruiting specialized neural mechanisms.

Thus, neuroimaging expectations in the study here developed would predict a reduction in the asymmetry in interhemispheric discourse processing in aging. Especially in discursive aspects that would pose more difficulty for elderly adults they would benefit from more bilateral activation as compared to younger adults' patterns, and/or from an extra recruitment of areas, in a more diffuse way. In other words, it is hypothesized that the amount and extent of hemispheric activation while performing the discourse task proposed in this study will be more important in elderly than in younger participants, as measured using NIRS; that is, a higher amplitude of signals for one recording site, and an increase in number of sites activated, especially for micro-structural processing – the most difficult level for elderly people - will be registered in the elderly participants' processing as compared to the young participants' one. In this level of text structure, a more bilateral activation is expected in order to compensate for the difficulty in processing.

The next section will focus on another aspect which, like aging, affects the organization of discourse processing in the brain, namely the proficiency attained in a second language.

2.3 THE REPRESENTATION OF DISCOURE PROCESSING IN BILINGUALS

Studies on bilingualism are relevant for a better understanding of how the neural representation of language takes place in a brain capable of storing and computing more than one language. In this sense, these studies go beyond the investigation of the single language context by leading a debate whose final aim is to achieve a deeper understanding of brain/language relationships, as pointed by Vaid and Hull (2002, p. 4). Moreover, they may contribute for a better understanding of how the brain processes language in general and of how the hemispheres differently process languages in particular (Beeman & Chiarello, 1998, p. 377), as well of how each language component functions in each hemisphere. In this way, this type of study may give fundamental foundations to the debate on symbolic versus connectionist paradigms in second language acquisition, as well as to the role of the allocation of cognitive resources such as attentional and working memory capacities in the acquisition of L2 aspects (Zimmer, 2007; Zimmer & Alves, 2006; Mota & Zimmer, 2005).

In this chapter, an overview of fundamental issues regarding bilinguals' language processing will be developed, finishing with a look into discourse processing in this population.

2.3.1 Fundamental issues under the scope of bilingualism

A bilingual can be defined as "an individual who has knowledge of and regularly uses two languages, although the two languages need not to be used in the same contexts or known to the same degree" (Vaid, 2002, p. 417). Paradis (1997) states that bilinguals, "speakers who use two languages with the fluency characteristic of native speakers, do not form a homogeneous group" (p. 348). The author affirms that this heterogeneity may be reflected in different aspects, such as the degree of proficiency, and may be influenced by the manner of acquisition, the degree of affective involvement, the context and frequency of use, and the structural distance between the two languages. Each of these factors may influence the representation and/or processing of the two languages.

As stated by Grosjean (2002), a bilingual is not the combination of two monolinguals, nor should its characteristics be studied in comparison to a monolingual. The bilingual uses the two languages separately or together, for different purposes, in different contexts and with different frequencies. The author then states that "because the needs and uses of the two languages are usually quite different, the bilingual is rarely equally or completely fluent in his/her languages" (p. 2).

Several interconnected aspects have been under the scope of studies developed by researchers of the bilingual brain, including studies of brain-damaged bilinguals' processing, a complementary investigation for a fully understanding of normal language organization in the bilingual brain (Ansaldo et al., in press). Research has investigated the cortical representation of first and second language, in order to verify whether the cortical substrate for language is the same in unilinguals and bilinguals, whether the

processing of non-native languages recruits additional or fewer brain regions as compared to the processing of the native language, as well as the role of different types of tasks in activating brain areas. Moreover, researchers have analyzed the role of age and form of acquisition (in natural or formal contexts), and the influence of proficiency level in language representation (Scherer & Ansaldo, 2006). These aspects will be discussed below.

Bilinguals can be divided in different groups in accordance with the organization of the *contents* of their implicit linguistic competence, that is, the contents of the grammar of their languages. These contents may be influenced by the manner of acquisition of each language (Ervin & Osgood, 1954, as cited in Paradis, 1997, p. 344), an assumption that leads to the postulation of the existence of three groups of language organization: coordinate, compound and subordinate organization; that is, when each language is acquired through interaction with native speakers in different contexts, the contents of implicit linguistic competence tend to be the same as those of each group of native speakers (coordinate organization). When both languages are acquired in a bilingual context, in which both languages are used interchangeably in all contexts, some aspects of their grammar may exhibit bi-directional interference (compound organization). Finally, when a language is acquired through translation in a first language environment, as occurs in a formal foreign language class at school, the second language will probably contain elements of the first (subordinate organization).

As stated by Paradis (1997), these three types of organization describe the contents of the grammar (phonology, morphosyntax, and the lexicon) but do not relate to the issue of cerebral representation of the linguistic system.

The degree of functional integration or separation of the two languages in a bilingual brain has been a prominent issue in research on bilingualism. An initial concern, though, pointed out by Paradis (2004, p.97), is that experimental research has looked into the question of lateralization of language without clearly stating what their concept of language is. According to the author, one can infer that researchers in general "had implicit linguistic competence, i.e. the language system, the code, the grammar in mind". Thus, prior to the discussion on lateralization, the author states that he conceives *language* (or linguistic competence) as referring to sentence grammar (phonology, morphology, syntax, and semantics), and *utterance* as referring to a sentence "used in context, which requires inferences from the situational or discourse contexts and/or from general knowledge (i.e. pragmatic features) in addition to grammatical processing, in order to arrive at an interpretation of its meaning". Paradis states that language (as defined above) is subserved by specific areas of the left hemisphere, while pragmatic aspects are subserved by the right hemisphere in right-handed bilinguals.

Widely accepted in the 1960s, the theory that suggested the development of a progressive lateral specialization for language, increasing from infancy to adolescence, has been abandoned after accumulated evidence indicating that cerebral lateral specialization is established from early infancy or even during fetal development and does not change over time. In early childhood, and what might be the case also for non-proficient bilinguals, most of the communication relies on pragmatic aspects and on an increasing number of lexical items, while grammatical aspects are rare. In these groups, there might be a greater activation of the RH, but as grammatical competence develops, it is processed mainly by the LH.

The same functions executed by both hemispheres in processing the first language are extended to the second language. Vaid and Genesse (1980, as cited in Vaid, 2002, p. 426) proposed a theory according to which

> Right hemisphere involvement will be more likely the later the second language is learned relative to the first, the more formal the exposure to the second language, and possibly, the earlier the stage of language acquisition. Left hemisphere involvement is more likely the earlier the second language is learned relative to the first, the more informal the exposure to the second language, and the more advanced the stage of acquisition.
>
> (Vaid & Genesse, 1980, as cited in Vaid, 2002, p. 426)

Cognitive and neuropsychological research has investigated bilinguals' language processing regarding hemispheres. Cognitive research in bilingualism has focused mainly on semantic representations, supporting the position that the two languages share a common semantic network (Francis, 1999), while neuropsychological research has focused mainly on whole language performance, including not only semantic processes but also phonological, syntactic, and other processes, as stated by Illes et al. (1999, p. 347-348). Mixed results have been obtained by behavioral hemispheric lateralization studies, brought by studies of clinical cases of aphasia recovery and by the neurosurgical literature (Illes et al., 1999).

Clinical cases of differential language recovery after stroke-induced aphasia in multilinguals have been used as evidence for separate cortical representations for languages; however, caution is needed in interpreting these data since the use of the language prior to the stroke and particular aspects of language that underlie the impairments should be considered. The neurosurgical literature has shown that naming in both languages can be selectively or simultaneously disrupted in cortical stimulation studies, but it has not discriminated the specific components of language that are shared or separate by hemispheres.

Illes et al (1999) argue that this difference in approach between cognitive and neuropsychological research has made it difficult to build a cognitive neuroscientific theory of bilingual language processing.

An important issue that underlies the studies of lateralization and language organization in the brain relates to the way our knowledge is stored, i.e., to our memory system. Language users need to combine two types of memories: the procedural and the declarative memory. Procedural memory relates to the unconscious and automatic use of language rule-governed features such as syntax, phonology, morphology and the lexicon of the language (Ullman, 2001, 2004), while declarative memory comprises properties such as the referential meaning of words and sounds of words. The two systems are separable, but it does not mean that languages are differently located. Imaging techniques and cortical stimulation have confirmed the existence of overlapped networks of multiple languages in the left hemisphere, with greater differences for less proficient individuals. In other words, the two languages in the brain of a bilingual are neurofunctionally independent, "though their representation is not anatomically distinct,

at least not at the gross anatomical level (even though each language system is likely to be subserved by distinct neural circuits)" (Paradis, 2004, p. 349).

Paradis also states that, comparing bilinguals' language processing to monolinguals' one, "*what* is represented and processed may be different (the internal structure of the contents may differ), but *how* it is processed (i.e., the principles by which languages are represented and processed) is not." That is, "in different types of bilinguals, what differ are not the types of mechanisms but the individual's grammar, […] not the *organization* of the system but its *contents*" (Paradis, 2004, p. 190).

Thus, there is no evidence to postulate qualitative differences between the cerebral structures and/or mechanisms of bilinguals and unilinguals. Differences may occur in terms of a greater reliance on pragmatics and/or metalinguistic knowledge, and thus involving the RH to a greater extent in the first case and structures subserving the declarative memory system in the second. These are quantitative differences, once they generally emerge due to a lack of content, that is, individuals whose L2 is not native-like, like children in the process of acquiring their native language, rely more heavily on pragmatic and/or metalinguistic clues in order to compensate for lack of grammar (implicit linguistic competence).

To sum up, we may claim that in the bilingual brain, the *form* of the representation of the L2 and its *contents* may differ from the L1 norm, but the *manner* in which these representations are subserved (in terms of mechanisms and neuropsychological processes involved) is the same for all languages.

Studies on language lateralization have focused their attention on aspects correlated with language organization in the brain, such as age and form of acquisition,

and proficiency levels attained by bilingual individuals, to be discussed in the following sections.

2.3.1.1 *Studies on the role of age and form of acquisition*

The assumption that the age of acquisition influences the rate of learning and the degree of proficiency attained (Krashen, Long & Scarcella, 1982, as cited in Illes at al., 1999) is not shared by all second language acquisition researchers, especially those who have investigated the role of communicative form instruction. However, some studies have shown that late bilinguals are typically less proficient in the L2 than early bilinguals (Johnson & Newport, 1989, as cited in Illes et al., 1999). This assumption has led Illes et al. to state that although research in the effects of age of acquisition in language representation in the brain "has provided no evidence that semantic processing differs for languages learned early or late, it suggests that any cognitive or neural differences between L1 and L2 should be greater for late than for early learners" (p. 349). As stated by Abutalebi et al (2001, p. 181), "the phonological and morphological components seem particularly deficient when L2 is learnt later in life, whereas the lexicon seems to be acquired with less difficulty after puberty", what could be an evidence that L2 neural organization may vary as a function of age of acquisition.

Regarding lexicon acquisition, Fabbro et al. (2001) state that lexicons of L1 and L2 are macroscopically represented in the same brain areas regardless of the age of acquisition. Thus, both L1 and L2 lexicons are stored in declarative memory systems, which are represented in the left cortical associative areas subserving language functions

(Ullman et al., 1997). However, morphosyntactic aspects may be organized in different systems according to the acquisition versus learning modality. According to Neville et al., (1992, 1997) and Kim et al. (1997, studies cited in Fabbro, 2001), "the representation of grammatical aspects of languages seems to be different between the two languages if L2 is acquired after the age of seven and automatic processes and correctness are lower than those of the native language" (p. 219). This finding is in line with the idea that the acquisition or learning modality seems to determine a different participation of procedural memory systems versus declarative memory systems. If both languages are acquired in naturalistic environments and both are at a high level of proficiency, their phonologic and morphosyntactic aspects are stored in procedural memory systems, mainly left-lateralized in the brain. On the other hand, traditional L2 learning after the age of seven, combined with limited proficiency in production, seems to rely mostly in the declarative memory system, as mentioned by Fabbro et al. (2001, p. 219), recruiting prominently right-lateralized areas in the brain when pragmatic aspects come into play (Paradis, 2004).

Hull and Vaid (2001) developed a meta-analytic study comparing bilinguals and monolinguals' language lateralization. Their literature review has shown some evidence that early non-proficient bilinguals are more bilateral for language as compared to late fluent bilinguals, who were left lateralized. The reduced number of studies testing moderate and low proficiency late bilinguals did not allow certain generalizations to be made with some degree of statistical confidence.

Four studies have directly compared early and late bilinguals mastering the same languages (Chee et al., 2001, Hernandez et al., 2001, Bevelier et al., 1998, and Kim et

al., 1997, as cited in Vaid & Hull, 2002, p. 12). However, although all of them have found some differences between the groups, these studies do not allow any firm conclusions due to the fact that other variables were not held constant, thereby making it difficult to attribute the results to age effects alone - different levels of proficiency and different types of tasks may have contributed for the emergence of different results.

Bialystok (1997) also alerts to the importance of a careful analyses of different factors affecting bilinguals' language representation before attributing research results to age of acquisition. She emphasizes the necessity of considering three determinant issues, namely 1) the correspondence between structures in the L1 and in the L2 (the more similar, the easier the assimilation of the L2 will be, independently of the age factor); 2) the length of residence (the amount of time spent using the L2), and 3) the amount of formal education in the L2. These factors have barely been considered in studies on the age of acquisition factor. Fledge et al. (1999) also emphasize the role of formal education in L2 and of the exposure to and use of the second language in language organization in the bilingual brain, thus not being in favor of the existence of a maturationally defined critical period.

Finally, Bialystok (1997) states that testing methods have shown to bring different results as well. To illustrate this, she cites two studies developed by Johnson and Newport, who attributed their results to the age of acquisition factor. Participants in their written presentation of the task (Johnson, 1992) scored much higher than when performing the same task in an aural mode (Johnson & Newport, 1989). Still concerning these studies, she raises the question of how age effects could be responsible for affecting the twelve grammar structures tested in the task in different ways, a criticism to

the fact that similarities and differences between the two languages had not been controlled.

To illustrate the necessity of a careful analysis of concurrent factors before attributing results to the age of acquisition factor, one could cite the reflection proposed by Bialystok (1997, p. 134) in this concern:

> Age differences in second language acquisition ability are inconsistent, sometimes to the advantage of older learners, but appearing only on certain kinds of tasks that assess specific aspects of knowledge. The documented cases of perfect mastery of a second language achieved by late learners are not anomalous exceptions to a biological law or extraordinary feats by rare individuals with an unusual and prodigious talent. Rather, they are quite ordinary occurrences that emerge when conditions are favorable. In the absence of more compelling evidence, it is prudent to assume that successful second language acquisition remains a possibility for all those who have learnt a natural language in childhood and can organize their lives to recreate some of the social, educational an experiential advantages that children enjoy.
>
> Bialystok (1997, p. 134)

The next section will discuss the role of L2 proficiency in the organization of the two languages in the brain.

2.3.1.2 *Studies on the role of different levels of proficiency*

The degree of proficiency in a second language acquired after the first language has been mastered seems to clearly influence the organization of languages in the bilingual brain. As stated by Illes et al. (1999), "several cognitive studies indicate that the organization of the second language changes during the acquisition processes" (p. 349). For example, in early stages of learning, L2 vocabulary is primarily acquired through association with the translation of the words in the L1, whereas, in later stages, vocabulary acquisition is more concept-mediated, that is, L2 words are associated with their meanings. Furthermore, according to Paradis (1998), in both children and adults at the first stages of L2 learning, the RH seems to be more involved in verbal communication processes because beginners make pragmatic inferences to compensate for the lack of implicit linguistic competence. In other words, "speakers of a fluent, albeit weaker, second language will rely on pragmatics (and hence their right hemisphere) and metalinguistic knowledge (and hence their declarative memory system) to a greater extent than unilinguals and (early) bilinguals" (Paradis, 1997, p. 348).

As stated by Vaid and Hull (2002), one can assume that the closer the bilinguals' level of proficiency in their two languages, the closer the overlap in activation patterns. Thus, "highly proficient bilinguals should show consistent activation in both their languages" (as shown by studies developed by Chee et al. (1999) and Illes et al. (1999)

investigating highly proficient bilinguals, which showed overlapping L1 and L2 activation patterns), "whereas less proficient bilinguals should show less overlap in hemodynamic response in their two languages, with L2 activations being more variable" (p. 12) – as reported in Dehaene et al. (1997), a study presented below.

Some studies have illustrated the occurrence of a greater bilateral activation of some hippocampal structures registered in individuals with a moderate knowledge of L2 acquired in formal contexts. Two of these studies are Perani et al. (1998) and Dehaene et al.'s (1997). The first study found that less proficient bilinguals showed very different activation patterns when listening to L1 and L2 speech, with L2 no different than an unknown language, whereas highly proficient late learners showed no differences between L1 and L2. Thus, it seems to be the case that as an L2 learner becomes proficient in L2, the cortical implementation of language processes becomes increasingly similar to that of L1. Perani et al. (1998) state that

> […] a possible interpretation of what brain imaging is telling us is that, in case of low proficiency individuals, multiple and variable brain regions are recruited to handle as far as possible the dimensions of L2 which are different from L1. As proficiency increases, the highly proficient bilinguals use the same neural machinery to deal with L1 and L2.
>
> (Perani et al., 1998)

The second study (Dehaene et al.'s, 1997) corroborates the assumption that a variability of language organization in the bilingual brain is a consequence of different degrees of proficiency and forms of acquisition. In their study, they analyzed brain activation during short story listening tasks in French (L1) and English (L2) in subjects with moderate command of L2, who have learned the L2 in school contexts. The results confirmed the hypothesis of a left hemisphere representation for L1, whereas late acquisition of an L2 (with lower levels of proficiency) caused great variability in its cortical representation (from complete right lateralization to standard left lateralization for L2).

2.3.1.3 *Considerations about the correlation between age and form of acquisition, levels of proficiency and languages representation*

From the findings presented above, it is possible to conclude that, as mentioned by Fabbro et al. (2001), the representation of languages in the bilingual brain seems to be dependent on proficiency in the two languages and independent of the age of acquisition (p. 218) and probably dependent on the form of acquisition if high levels of proficiency have not been attained. Similarly, the PET study designed by Perani et al (1998) to compare the effect of age of acquisition in comprehension of orally presented stories in two languages has shown that "attained proficiency is more important than age of acquisition as a determinant of the cortical representation of L2" (p. 1841).

Consequently, all these factors may also concur and therefore be observed as possible variables when investigating normal and impaired bilinguals' language

processing. As stated by Paradis (1997), "higher cognitive functions in general, and language in particular, tend to exhibit considerable diversity in degree of proficiency as a result of a number of dimensions of variability (genetic, environmental, affective, cognitive, hemispheric, strategic, mnemic)" (p. 347). The author affirms that, despite the occurrence of this variability in first language acquisition, it is uniform across languages and across normal individuals, but is much irregular in relation to L2 acquisition, leading to a wider range of variation in degree and quality of achievement.

2.3.2 The processing of language components by bilinguals

Many findings of different patterns of activation between L1 and L2 are consistent with an implicit/explicit account of language processing. Different patterns of activation between L1 and L2 processing are compatible with the idea that, insofar subjects have weaker implicit linguistic competence in their L2, they rely more heavily on metalinguistic knowledge and pragmatics (Paradis 1997, 2004). This is reflected by the additional activation of mesial temporal, parahippocampal, and prefrontal areas in the LH (known to be involved respectively in declarative memory and conscious control) and areas of the RH (known to be involved in pragmatic inference) (Paradis, 2004, p. 185), what shows a greater dispersion and weaker activation within the traditional perisylvian language areas during the processing of a weaker L2. Thus, according to Paradis,

[…] one of the most robust findings in bilingual neuroimaging studies based on the processing of units longer than single words or phrases is the greater involvement, in later-learned languages[4], of regions subserving declarative memory and pragmatics.

(Paradis, 2004, p. 186).

This assumption can also be explained by the evidence of homogeneity across subjects in the processing of their L1 – what reflects the automaticity of the process - relative to the great variability in the processing of their L2 – an evidence of the application of a varied number of compensatory strategies recruited in order to cope with a more limited implicit linguistic competence (Scherer et al., 2006c,d). Thus, procedural memory items will be activated in circumscribed cortical areas involving subcortical and cerebellar regions, while declarative memory will be represented more diffusely, involving frontal control mechanisms and parahippocampal mnemic processing mechanisms. This idea led Paradis (2004) to state that "the properties of what is represented (such as whether it is conscious or not) determine where and how it will be represented and processed" (p. 186).

There are at least five neurofunctional mechanisms directly involved in normal language use, as stated by Paradis:

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[4] Research has not always corroborated the idea that later-learned languages would be differently organized in the brain (Vaid, 2002); rather, it has emphasized the role of proficiency in this anatomically and organizationally different distribution of L1 and L2. Therefore, it is important to state that one cannot always associate later-learned languages to lower levels of proficiency, since evidences have shown that one can attain high levels of proficiency learning the L2 after puberty.

(1) The part of the cognitive system which formulates the message to be verbalized and decodes the message to be understood; (2) the implicit linguistic competence system, which provides the grammar (phonology, morphology, syntax and semantics); (3) the metalinguistic system, which monitors the correctness of the sentences (about to be) produced, and in some circumstances also provides conscious knowledge of surface structures to be implemented or understood; (4) the pragmatic system, which selects the linguistic and paralinguistic elements most appropriate to the message to be conveyed and infers the interlocutor´s intention from the various contexts of the utterance; and (5) the motivational system without which no utterance would ever be produced.

(Paradis, 2004, p. 226)

Paradis postulates that these systems constitute a neurofunctional module that interacts with other modules in parallel or in rapid succession, with the output of one possibly serving as input for the other. Complex tasks are performed in collaboration with a number of independent neurofunctional modules, each one subject to selective impairment. According to this theory, each language of a bilingual individual is represented as a complex subsystem comprising several modules (Paradis, 2004).

According to Paradis, the more a word, an expression or a language is used, the lower its activation threshold will be. If a language is not used for a long time, its activation threshold level will be raised, causing difficulty in using it. If a determined word is used more frequently or has more recently been used than its translation equivalent, its threshold level becomes lower, and the word is selected when the speaker is in a bilingual mode of communication. This phenomenon may also cause word-finding problems when the speaker is communicating with unilinguals of a certain language. From these findings, Paradis (1997, 2004) derives two conclusions: 1) the availability of a word, an expression or a language is directly related to the frequency and recency of its use, and 2) when a language is not available, it is not physically destroyed but physiologically inhibited.

When encoding or decoding a message, bilingual speakers have direct, automatic access to one or the other of their languages (Paradis, 1997). Once it is accessed, the neurological subsystem subserving the other language is inhibited in order to raise its activation threshold to a point that makes self-activation difficult or impossible, but not high enough to prevent its activation by external verbal stimuli. As proposed by Paradis, messages are directly encoded and decoded in the selected language, without involving translation, and words do not have to be "tagged" as belonging to Lx or Ly in order to have their meanings activated.

It is particularly important to analyze the processing of two complex language components by bilinguals, namely semantics and pragmatics. Semantic and pragmatic language properties are closely related whenever meaning is processed at the sentence and discourse levels. Semantics refers to the aspects of meaning (the content of words

and signs shared within and among communities) that are expressed in a language. Pragmatics, as already mentioned, is the study of the meaning of an utterance in its context of production. It relates to meaning of the unsaid portion of the utterance, based on what can be inferred from the context of use and general knowledge, with observance to the speaker's intention. Pragmatics also relates to the structure of the discourse, inasmuch as it relies on implications and inferences. Pragmatic aspects are an integrating part of our every-day communication in a great variety of situations. Many times we do not say what we mean, or we say less than what we mean, and expect our interlocutor to understand exactly what we mean.

The same sentence can have many different meanings, which will vary in accordance with the circumstances of its production. Pragmatic capacity to infer meaning from nonlinguistic cues is as implicit as linguistic competence is, but is acquired prior to it. For instance, children know how to identify pragmatic cues long before they are able to say their first words. Paradis (2004) establishes a parallel comparison between the development of conceptual and pragmatic competence, by affirming that "just as concepts are shaped and refined by language-specific constraints, pragmatic capacity is shaped and refined by cultural-specific implicit pragmatic conventions" (p. 18). Therefore, people from different cultures may infer different meanings from the same utterance produced in a particular context. This also explains why foreign language speakers are more likely to understand the semantic than the pragmatic meaning of utterances, since the latter is acquired from practice in natural cultural settings or in formal instructional settings designed to focus on this aspect.

As one can conclude from the discussion developed so far, in which many concurrent factors that interplay with bilinguals' language system were presented, the study of discourse processing by bilinguals comes out as being a challenging domain, since discourse itself represents the highest level of complexity in language processing. A much reduced number of studies have been developed in this field. Recently, some imaging studies have tried to shed some light on how hemispheric cooperation takes place in discourse comprehension and production by bilinguals, which will be the topic of the next section.

2.3.3 Discourse processing by bilinguals

2.3.3.1 *Evidence from behavioral studies*

A study developed by Chen and Donin (1997) investigated the role of language proficiency and of domain-specific knowledge on written discourse processing by bilinguals. They found out that domain-specific knowledge was more relevant for the understanding of higher order text computations, such as discourse processing, than at more local syntactic and semantic computations. Yet language proficiency consistently affected lower-order processing, but was not decisive on the higher order level.

Another study, conducted by Walter (2004), has investigated the transfer of reading strategies from L1 (French) to L2 (English) by proficient (upper-intermediate level) and less-proficient (intermediate level) L2 speakers. Her study revealed that proficient readers succeeded in applying successful reading strategies for coping with L2

texts, while less-proficient ones did not, even when they had no problems in processing the individual sentences of the texts. She concluded that high-proficient L2 speakers succeeded in transferring to the L2 the ability to build well-structured mental representations of texts and that this ability is linked to the development of working memory in the L2.

2.3.3.2 *Evidence from imaging studies*

Research has aimed to analyze discourse processing by bilinguals, mainly with the use of fMRI and PET. The charts below present a summary of some of the main studies developed on orally presented discourse comprehension (Table 3) and discourse oral production (Table 4) – studies at the sentence and word level were not included. Neuroimaging studies on bilinguals' comprehension of visually presented texts are very rare, probably as a consequence of the limitations imposed by imaging techniques to this type of modality. An example of a study of visually presented discourse comprehension by bilinguals is the fMRI investigation developed by Kobayashi et al (2006), who analyzed the processing of written texts dealing with the comprehension of theory of mind stories by Japanese-English bilinguals and American English-speaking monolinguals. They intended to examine the influence of culture/language on neural bases of theory of mind processing, since incongruent findings have been reported in the literature concerning its comprehension by populations with different cultural backgrounds. In their experiment, both cultural/linguistic groups recruited several neural correlates including medial prefrontal cortex and anterior cingulated cortex; however,

some other brain areas such as the inferior frontal gyrus were employed in a culture/language specific manner, suggesting that the way adults understand theory of mind is not entirely universal.

The analyses of the data brought by the studies on comprehension and production in an oral mode reflect, overall, a more diffuse activation bilaterally, especially on the RH, when processing L2 in lower levels of proficiency and in late (after infancy) L2 acquisition. Regarding L1 processing, perisylvian areas were more activated. Another important finding relates to a possible differentiation of functioning within Broca's area. Some of the studies presented below suggest a different specialization within Broca's area (namely BA44 and BA45), which may be related to age and context of L2 acquisition, to the nature of the language, or still, as reported by other studies, to task or language domain specificities, as observed in a study developed with monolinguals by Newman et al (2003), which has shown different patterns of activation within Broca's area for different syntactic and semantic conditions in sentence processing.

Table 3: Review of imaging studies on bilinguals' oral COMPREHENSION of discourse

Researcher(s) / imaging tool	Participants	Type of discourse processing	Brain sites	Results
Perani et al., 1998 PET	G1=L1 Italian, L2 English, high proficient, acquired after age 10 G2=L1 Spanish, L2 Catalan, high proficient, acquired before age 4	Story listening in L1/L2	Both groups = similar areas G1=*Late L2*= listening to L1 (Italian) = left temporal lobe (temporal pole, superior temporal sulcus, middle temporal gyrus, hippocampal structures); listening to L2 (English) = similar to L1 in left temporal pole + bilateral hippocampal structures G2=*Early L2*=bilateral temporal poles, hippocampus, lingual gyrus; left ST sulcus, inferior parietal lobule; lingual/cuneus, cerebellum; comparing languages, significant differences in RH= L1- middle temporal gyrus; L2- superior parietal lobe and hippocampus	G1= no differences between L1 and L2 G2= greater right middle temporal gyrus for L1 and greater right hippocampal and superior parietal lobule for L2
Dehaene et al., 1997 fMRI	L1=French; L2=English, moderate proficiency, L2 acquired after age 7	Story listening in L1/L2	L1= left temporal pole (left superior temp. sulcus and middle temp. gyri); L2= variable left/right temporal and frontal areas (sometimes only on the RH)	More widespread activation in the left and right frontal and temporal regions in L2
Perani et al., 1996 PET	L1=Italian; L2=English, moderate proficiency, L2 acquired after age 7	Story listening in L1/L2	L1= perisylvian (inf. frontal gyrus, sup. and middle temporal gyrus, temporal pole, angular gyrus) + right cerebellum L2= reduced activation in right superior and middle temp. gyri than in listening L1; bilateral parahippocampal region	The brain network for L2 listening reflects great inter-subject variability; the patterns of activation can be ascribed either to age of acquisition

Table 4: Review of imaging studies on bilinguals' oral PRODUCTION of discourse

Researcher(s) / imaging tool	Participants	Type of discourse processing	Brain sites	Results
Watterndorf et al., 2001 fMRI	8 multilinguals (3 languages), divided in early and late L2 acquisition	Recounting of the previous day's events	Different coativation patterns in Broca's area (BA 45 and 44) for the 3 languages of the same participant	Different languages may have different demands on brain areas involved with language processing Further study: whether these differences are due to the nature of the languages or to time and context of languages learning
Kim et al., 1997 fMRI	L2 proficient bilinguals (6= early infancy, 6= adulthood); varied pairs of languages	Recounting of the previous days' events	ROIs: Broca and Wernicke – see results	*In Broca's area, the 2 languages are not processed in the same place for late L2 acquisition *In Wernicke's area, there is no or very little difference in location regarding age of L2 acquisition

Due to its circumscribed functioning, caution is needed when analyzing and interpreting data from neuroimaging studies: additional activation in the left parahippocampal gyri and RH, besides the one observed in those areas that subserve the linguistic system per se (the left perisylvian area), may reflect the use of non-linguistic compensatory mechanisms. In other words, activation in these additional areas may be task-dependent and may reflect the absence of a linguistic capacity, compensated for by the use of pragmatic and metalinguistic knowledge, a process also observable in the processing of a weaker language by a bilingual, as already mentioned (Vaid & Hull, 2002).

Another discussion that should be addressed when we intend to analyze neuro-imaging data on language processing is the relation between language components and our procedural and declarative memory. As previously discussed, Paradis (1997, 2004) states that our procedural memory is constituted by the implicit competence, which underlies the performance of motor and cognitive skills, and relates to internalized procedures which permit the automatic performance of a motor or cognitive task. Our declarative memory subserves everything that can be represented at the conscious level, and subsumes both our episodic memory (memory of specific, consciously experienced events) and our semantic memory (the individual's general encyclopedic knowledge, including the knowledge of the meaning of words); in other words, declarative memory comprises one's encyclopedic knowledge (knowledge of the world) and one's episodic memory (past experiences). The author claims that studies of patients' recovery patterns have shown that declarative memory is independent of procedural memory, and that vocabulary is at least in part subserved by declarative memory, whereas the

morphosyntactic and phonological aspects of language (implicit and rule-governed) are mainly subserved by procedural memory. Therefore, the organization of procedural and declarative knowledge is intrinsically related to L2 appropriation and organization, as well as to bilingual aphasia. As for the language components, Paradis (2004, p. 7) states that they comprise phonology, morphology, syntax and semantics (known as our linguistic competence), as well as other three functions directly involved in the production and comprehension of utterances, namely metalinguistic knowledge, pragmatics, and motivation. According to the author, what the literature has shown over the past decades is that language (as defined above) is mainly subserved by specific areas of the LH, while pragmatic aspects are subserved by the RH in right-handed bilinguals. Thus, left-hemisphere-brain-damaged patients have difficulty mainly with the linguistic components, while right-hemisphere-brain-damaged patients have difficulty especially with the pragmatic components.

From this discussion, according to Paradis, one can assume that the more prominent activation of the RH in non-proficient bilinguals may reflect an extra activation of pragmatic aspects to compensate for a lack of procedural and automatized knowledge of the L2. In the case of discourse processing itself, one may expect an even more relevant demand on the RH, which is implicated in discourse processing also in the mother tongue, as already stated.

The inter- and the intra-hemispheric dynamics which take place when the brain copes with language processing has been the focus of research which aims to understand why and when both or a single hemisphere is activated, as it has already been discussed in the case of the aging brain. Research has tried to analyze which types of language

processing demands the recruitment of extra areas in the same hemisphere and/or of the counterparts in the other one. One of the models that have shed some light to this discussion is the Banich Model, to be presented in the next section.

2.3.3.3 *The Banich Model[5] and language proficiency*

Research developed in the last two decades has revealed the existence of brain areas which seem to be specialized in determined cognitive functions, and posits as well the fact that one specific area can be implicated in different cognitive tasks. Moreover, studies have pointed to a parallel activation of different areas, all contributing at the same time to the computation of a task (Keller et al., 2001). Findings like these have been brought by the recent boom in neuroimaging studies. However, the nature of this interaction is still to be explained; that is, research is starting to investigate how and why certain areas are recruited, and the sequence by which this connection is done. The use of DTI (Diffusion Tensor Imaging), a technique able to tract specific regions of interest and measure diffusion characteristics along these tracts, seems to be a promising tool to engender this type of investigation.

Although the existence of a hemispheric specialization for certain computations is well known, it is important to consider that a majority of functions can be performed by both brain hemispheres (Eviatar & Zaidel, 1994). Thus, both hemispheres may contribute for a task, even if one of them is more proficient in doing it.

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[5] The name used to designate this model in this dissertation refers to the author of this theory. A specific name to designate it was not found in the literature so far.

This bilateral distribution advantage (BDA), as proposed by Copeland and Zaidel (1996), has been accounted for the "division-of-labor" models (Liederman, 1998), which attribute the bilateral advantage to the physical separation of interfering inputs processed in parallel by both hemispheres, and by the "common-resource-pool" models, which assume that the hemispheres work in a complementary way, each one assuming the task components for which it is best suited (Grimshaw, 1998).

One aspect that may interfere in the type of processing mode (inter- or intra-hemispheric) is the level of complexity of the task. Maertens and Pollmann (2005), Banich et al (2001), Banich and Weissman (2000) and Weissman and Banich (2000), based on data brought mainly by experiments using letter matching and geometric forms matching paradigms, postulate that extra areas, generally the hemispheric counterparts, are activated when complex tasks have to be solved. That is, they assume that the hemispheres "couple" and "de-couple" according to the complexity of the task. If one single region, which is normally activated for developing a standard task, is able to "do the job" alone, no extra recruitment will be required; that is, in general, for easy tasks, there would be an intra-hemispheric advantage in processing. On the other hand, if the task to be performed is complex, a wider activation, involving in general the counter-part in the other hemisphere, will occur; that is, for complex tasks, there would be an inter-hemispheric advantage. The occurrence of intra- or inter-hemispheric processing would be related to the costs and benefits of sharing or not information through the corpus callosum. The most efficient mode of processing is always the one adopted.

Thus, the Banich Model bases its assumption about the BDA in two concepts: computational complexity, which refers to the "transformations, operations or

computations needed to perform a task" (Belger & Banich, 1998), and processing efficiency, which refers to the amount of resources needed to carry out those operations. These two aspects will determine the mode of task processing. According to this model, increasing practice with a task may not diminish the complexity of the task, but may diminish the amount of resources needed to develop those computations. Thus, automatization may increase processing efficiency (Maertens & Pollmann, 2005), and may reflect a transition from algorithm-based performance to memory-based performance (Logan, 1988, in Maertens & Pollmann, 2005). The authors consider, then, that "a division of processing between the cerebral hemispheres may be most advantageous early in practice, because algorithmic processing involves more computational steps than direct memory retrieval" (p.185).

Extending this theory to bilinguals' language processing, one may assume that proficiency level may play a crucial role in the interhemispheric dynamics for L2 processing. In lower levels of proficiency, due to an absence of automaticity in language tasks execution, extra resource recruitment is needed, which may explain the higher RH activation and extra areas recruitment registered in the processing of language components in the L2. In this way, this model may represent another way, not excludent though, of explaining the dichotomy of procedural versus declarative memory processing, proposed by Paradis and others. Similarly to that assumption, this model suggests that non-automatized and more demanding tasks, which require a conscious effort, may recruit complementary regions in the brain, in general the counterpart in the other hemisphere.

In the same line, the theory may offer a possible explanation for the higher RH activation observed in elderly research participants. The extra and sometimes bilateral activation may represent, as already discussed in the section on the HAROLD Model, an extra effort to maintain similar levels of performance showed by younger adults. That is, determined tasks' execution may demand and extra effort in aging, requiring the activation of extra areas, and, in special, as already shown by the literature, as previously discussed, of the RH.

It is important to state, though, as mentioned by Weissman and Banich (2000), that there could still exist other possible reasons for a higher bilateral activation measured by imaging techniques. According to the authors, it could suggest: 1) each hemisphere working independently in a task; 2) different representations (e.g., visual or verbal) and their associated neural processors that are used to perform a task; 3) a *mandatory* (and not an "optional") choice if the extra processes required to perform a more complex task are in the opposite hemisphere; and 3) in the case of aging, different strategy allocation rather than differences in some optional neuronal recruitment (p. 43). As the studies on the inter- and intra-hemispheric dynamics in cognitive processing, including language, are still very recent, they represent a fruitful arena for further research, which should include, among others, issues as those mentioned above.

Relating the assumptions proposed by the Banich model to the study here developed, concerning discourse processing by non-proficient bilinguals, it is possible to hypothesize, as mentioned in the hypotheses presented in Chapter 1, that the amount and extent of hemispheric activation while performing a discourse task will be more important in non-proficient L2 speakers than in native speakers young adults, as

measured using NIRS. In other words, it is expected a more relevant participation of brain sites in terms of amplitude and number of sites involved in non-proficient bilinguals' reading performance than in native speakers' one, with a relevant participation of the RH and of hemispheric homologous areas in more demanding types of processing, in this case, higher order textual structures (macro-propositional level and situational model).

The next chapter of this dissertation will present the method adopted for the development of the experiment designed to investigate discourse processing by non-proficient bilinguals and elderly individuals.

CHAPTER 3

METHOD

This chapter presents the experiment carried out at the Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal (CRIUGM), a research center affiliated to the University of Montreal. The experiment was designed to investigate discourse processing in elderly and in moderate-proficiency L2 readers, by the use of NIRS. The chapter describes the characterization of the participants, the materials adopted, as well as the procedures for data acquisition and analysis.

3.1 PARTICIPANTS

Young participants were recruited at universities in Montreal, especially at McGill and Concordia University (mainly frequented by English speaking students) and at the University of Montreal, where mainly the young French native speakers were recruited. Elderly participants were recruited mainly from a file of volunteers who had already participated in fMRI or behavioral studies at the institute with other researchers, and others volunteered after reading the announcements of the research at the institute or at the near hospital.

These were the characteristics of the participants of the three groups (Table 5): 10 young adults, French-native speakers, (YF) (21-36 years old, average 25.6 years), 10 elderly adults, also French-native speakers (EF) (63-73 years old, average 67.7), distributed evenly in the groups with a balanced number of males and females, both groups speaking "Québécois" French.

Table 5: Characterization of the research participants, divided in 10 per group. (YF = young French native speakers, YE = young English native speakers, EF = elderly French native speakers; AoA = age of acquisition of French as L2; Form.Ed.L2 = years of formal education in French; Prof.TestL2 = percentage of correct responses in standard French test (DELF B1) to measure proficiency in L2 (French) reading; NA = non-applicable)

	Gender	Age (years)	Schooling (years)	AoA	Form.Ed.L2 (years)	Prof.Test (%)
YF	6 males	21-36 (25.7)	15-22 (17.3)	NA	NA	NA
YE	6 males	21-34 (24.2)	13-20 (16.6)	9-16 (11.2)	4-12 (6.6)	60-88 (74.8)
EF	3 males	63-73 (67.7)	12-19 (14.7)	NA	NA	NA

The third group was formed by young adults with an intermediate proficiency level in French – the bilingual group. The group was composed of 10 young adults, English-native speakers (YE) (21-34 years old, average 24.2 years). Some important aspects regarding their exposure, instruction and usage of French as an L2 were collected by the aid of the questionnaire especially designed for this aim (see Appendix B), whose data are now presented. Age of L2 (French) acquisition varied from 9 to 16 years old (11.2 years in average). All YE participants received formal education in French at school (4 to 12 years, 6.6 in average), in the secondary course (in immersion

programs), and/or at university, where some had classes taught in French and/or attended French classes. Due to the necessity of learning French to adapt to the French-speaking environment, some participants had also resorted to extra private courses in French, or attended the program offered by the government of Quebec, which aims to aid the adaptation of immigrants, coming from other provinces in Canada or from abroad, to the francophone cultural and linguistic environment. They were exposed to and used French for hours at daily bases, by reading, talking to friends and people at work/school, watching TV, among other activities, and reported using both languages (French and English) regularly and in different contexts, such as at university and at work. Five participants reported to use mainly English at home, while the other five ones informed that they use both languages at home.

They gave themselves a grade 3, in average, (grades varying from 2 = "very good" to 4 = "regular") to evaluate their ability in reading comprehension in French (3 meaning "good", in a scale of 1 = "excellent" to 5 = "poor"). Table 6 presents participants' self-evaluation regarding their language abilities in French, as measured by the questionnaire applied. They had all an intermediate level of proficiency in reading in French, as attested by the DELF B1 test (Part 2 – reading – "compréhension des écrits") (Appendix A), with an average of correct responses ranging from 60 to 88% (average of 74.8%).

Table 6: YE (young adults English native speakers) self-evaluation of their performance in the four language abilities (data from the questionnaire)

	speaking	listening	reading	writing
YE: Self-evaluation of performance in the four language abilities				
YE1	4	4	3	3
YE2	3	3	4	5
YE3	3	3	3	3
YE4	3	3	4	4
YE5	2	2	2	3
YE6	2	2	2	3
YE7	4	3	3	3
YE8	3	2	4	5
YE9	4	4	3	3
YE10	2	2	2	2
average grade	3.0	2.8	3.0	3.4

(Rates: 1= excellent; 2 = very good; 3 = good; 4 = regular; 5 = poor)

All participants from the three groups were highly instructed for their age level (YF = average of 17.3 years of formal education, YE = 16.6 and EF = 14.7).

They were all right-handers (as measured by the Edinburgh Handedness Inventory), and did not have any history of neurological or psychiatric disease.

They gave formal consent to participate in the study, by signing the informed consent, as requested by the ethics committee which controls research at the institute.

3.2 MATERIALS

3.2.1 Neuropsychological tests

A battery of neuropsychological tests was applied in order to make sure that the participants had comparable and within average scores of attention, inhibition and memory capacity, as predicted by the norms of the tests for their age and schooling groups. Thus, being excluded the hypothesis of influence of the cognitive aspects measured by the tests, behavioral and imaging data to be obtained through the experiment could be reliably evaluated.

The tests were presented in their original versions in French and in English, being the language choice dependent on the participants' native language, the same in relation to the language adopted for tests' application. The tests were 1) the Minimal Mental State Examination (MMSE) (Folstein et al., 1975), for aged participants only, 2) the Digit Span Test (Grégoire & Van der Linden, 1997), to test attention and short-term working memory, 3) the Trial Making Test – Part B (Reitan & Wolfson, 1985) and the Stroop Test (Spreen & Strauss, 1991), both to get data on inhibition and attention control, and 4) the Buschke Test (Buschke, 1984), translated to French by Gagnon (1993), to verify participant's working memory capacity, recall and learning ability. An additional test – the Edinburgh Handedness Inventory (Oldfield, 1971) – was applied in order to verify laterality dominance and ensure that all participants were right-handers with at least 75% of right dominance.

3.2.2 Questionnaire for bilinguals and standard test for proficiency in French

The questionnaire (Appendix B) was designed by this researcher, based mainly on a questionnaire developed by Silverberg and Samuel (2004), with some ideas

included from the work of Fledge et al (1999) and Paradis and Libben (1987). The focus of the questionnaire was to gather information about important complementary aspects to be considered for data analyses, such as age of L2 acquisition, parents and/or caretaker's first language, years of formal instruction given in the L2, daily exposure and use of the L2, type of instruction in the language, self-assessment in the four abilities (reading, writing, listening and speaking), previous language use, motivational factors that led to the acquisition of French, among other aspects.

To measure proficiency in L2 reading, besides the self-evaluation question specially designed for this in the questionnaire, a standard test of reading proficiency (the DELF -Diplôme d'études en langue française - B1, for intermediate proficiency in French) was applied. This test has been designed to verify language proficiency in the four areas; as our experiment aimed to tap the proficiency in L2 reading comprehension, only this part was applied to the participants (Appendix A).

3.2.3 The NIRS equipment

A multichannel continuous-wave optical imager (CW5) was used to obtain the measurements (TechEn) (Figure 2, below).

The imager had 16 lasers (8 in each optode, for right and left hemisphere) and 16 detectors (avalanche photodiode detectors – Hamamatsu C5460-01 - 8 per side). The laser intensities were driven at 16 different frequencies, generated by a master clock and separated by approximately 200 Hz steps, so that their signals could be acquired simultaneously by the detectors in parallel. Each laser delivered less than 5mW to the

tissue. A bandpass filter reduced 1/f noise and room light signal and the third harmonics of the square-wave signals. Then an analog-to-digital converter matched the signal levels with the acquisition level within the computer. Individual source signals were filtered afterwards by using an infinite-impulse-response filter with a 20 Hz bandpass frequency.

Figure 2: Illustration of the multichannel continuous-wave optical imager (CW5) (TechEn) used for imaging data acquisition
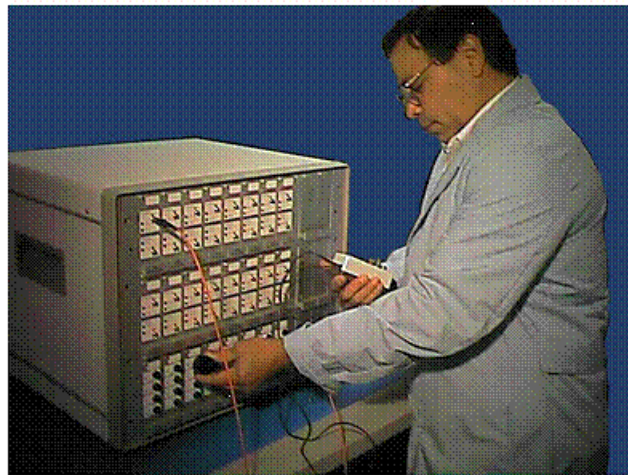
Light sources and detectors were coupled and arranged on the optodes, placed on the participants' head. The minimum source-detector separation was in average 3.0 cm.

3.2.4 Stimulus / task design

Stimulus: Thirty-six short narratives in French and one corresponding probe per passage were constructed for this study (Appendix C), some of them based on the task produced by Renault (2005). Texts were divided in three groups, according to the type of text processing the probes tapped (micro-propositional (MIC), macro-propositional

(MAC) or situational (SIT) level). There were twelve texts per group, six whose probe was "false" and six "correct" ones, randomly presented to the participants. After their construction, the texts and probes were judged by a group of 14 students (undergraduate, master's and doctoral students) of different domain areas (psychology, medicine and engineering), and the final judgment was given by 3 students from the Linguistic domain (one Master's student and two doctoral students). Following their suggestions, final adjustments were made to the probes and texts, in order to observe the use of standardized French, avoiding local expressions or less frequent and complex vocabulary, and the adequacy of the probes *versus* their classification was analyzed and confirmed. Extra three texts and probes, constructed and tested in the same way, were developed for the practice session (Appendix C). Three samples of the narratives, one per group, with their respective probes are presented below. The translation into English follows each text and probe.

Micro-propositional level

TEXT: Michaël est propriétaire d'une voiture verte depuis douze ans. Il l'aime bien et l'appelle Pierrette. La voiture de Michaël est très vieille et tombe en panne. Michaël est triste parce qu'il va devoir acheter une autre voiture.

Michaël has been the owner of a green car for twelve years. He loves it and calls it Pierrette. Michaël's car is very old and breaks down. Michaël is sad because he will need to buy another car.

PROBE : La vieille voiture de Michaël est de couleur bleue. (F)

The color of Michaël's old car is blue. (F)

Macro-propositional level

TEXT: Joanne a l'habitude d'être malade durant ses voyages, mais aujourd'hui elle se sent bien. Soudain, la plus jeune de ses filles tombe. Heureusement, un autre touriste la ramène à bord en la tirant par son gilet de sauvetage.

Joanne uses to get sick during her trips, but today she feels well. Suddenly, her youngest daughter falls. Fortunately, another tourist brings her back on board by pulling her by her life jacket.

PROBE : Joanne et sa fille sont des touristes en croisière sur un bateau. (V)

Joanne and her daughter are tourists traveling on a boat. (T)

Situational model

TEXT : Marie ne parle pas couramment le français. Elle a lu une offre d'emploi de réceptionniste dans un hôtel de Montréal. Elle va à l'entrevue mais sa candidature n'est pas retenue. Marie décide de prendre des cours de français.

Marie does not speak French fluently. She has read a job offer to work as a receptionist in a hotel in Montreal. She goes for the interview, but her application has not been taken. Marie decides to take French courses.

PROBE : Marie étudiera le français parce qu'elle adore cette langue. (F)

Marie is going to study French because she loves this language. (F)

a) Characterization of the short narratives

The short narratives contained from 3 to 5 sentences (average 3.9), with the number of words varying from 40 to 47 per passage (average of 41.9), the number of syllables varying from 61 to 78 (average of 70.1), and letters from 169 to 222 (average of 192.2). The amount of propositions within each passage was equated, varying from 15 to 18 (average of 17.3), since the number of propositions (even when there is control over the number of words) may interfere in the reading time (van Dijk, 1997). The complexity of the structures of the sentences was controlled for by the use of a simplified syntactic structure, through the use of coordinated short sentences, being embedded and passive sentences avoided. The different topics of the narratives depicted ordinary, daily events, in order to permit the elaboration of the situational model by all participants, independent of their age or background knowledge. Irony, indirect speech, metaphors, and theory of mind were aspects avoided in the texts.

b) Characterization of the sentence probes

The number of propositions (from 3 to 5), words (from 6 to 13[6]), syllables (from 11 to 24) and letters (from 32 to 59) was controlled, in order to allow statistical comparisons between the three conditions (see Table 7, below, for detailed information per condition). Probes focused either on the micro-propositions (MIC) (the surface representation of the semantic content of the text), on macro-propositions (MAC) (a higher hierarchical level, demanding simple inferences easily depicted from text

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[6] Although the number of words seems to vary largely within the probes, one has to consider that in French certain words are abbreviated and consist of a very reduced number of letters; moreover, there was not significant variability in the number of words comparing the three conditions.

structure) or on the situational level (SIT) (the representation of the essential and summarized content of the text, based on the readers' prior knowledge). These sentences asked for informative content of the passages to be inferred or condensed from the text and randomly referred to information present or not present. In the case of micro-propositional probes, the information requested was based on the predicate, not on the arguments of the sentences.

Table 7 shows the ANOVA analyses carried out to compare the number of words, syllables, propositions and letters in the probe sentences in the three conditions (MIC, MAC and SIT). No significant differences were found between conditions (p=.992 for words, p=.226 for syllables, p=.648 for propositions, and p=.782 for letters), reflecting similar patterns among the sentences regarding the number of their elements.

Table 7: Statistical comparison (ANOVA) of linguistic elements within the 36 probes used as stimuli

Statistical comparison (ANOVA) of linguistic elements within the 36 probes						
		Sum of Squares	df	Mean Square	F	Sig.
	Between Groups	,056	2	,028	,008	,992
words	**Within Groups**	121,500	33	3,682		
	Total	121,556	35			
	Between Groups	22,167	2	11,083	1,557	,226
syllables	**Within Groups**	234,833	33	7,116		
	Total	257,000	35			
	Between Groups	,389	2	,194	,440	,648
propositions	**Within Groups**	14,583	33	,442		
	Total	14,972	35			
	Between Groups	20,389	2	10,194	,248	,782
letters	**Within Groups**	1359,250	33	41,189		
	Total	1379,639	35			

Task design:

Figure 3 presents a graphic representation of the experimental design and the stimuli time-windows, taken for data analyses.

Task design

Total = 12 sets (text +probe+20s rest)

| Instruct. 20s | text 14s | probe 5s | + 20s | text 14s | probe 5s | + 20s | text 14s | probe 5s | + 20s | (…) |

488" → 510"   3 x ⇒ 3 blocs
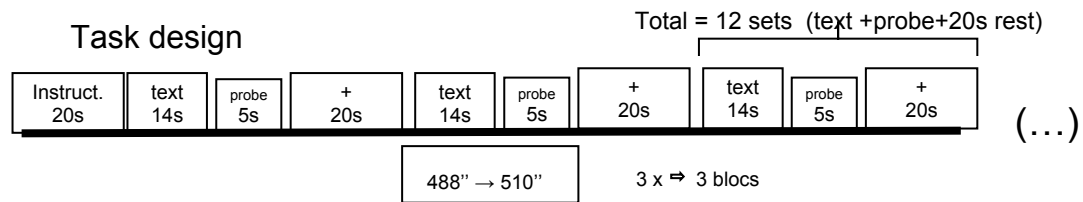
Figure 3: Graphic representation of the task design and of the timeline of measurements taken with NIRS

NIRS data acquisition: timeline

| Instruct. 20s | text 14s | probe 5s | + 20s | ( ) | 488''→ 510'' |

Time windows for analyses

| 35-59s | (14s) | 74-98 | (14s) | 113-137 | 152-176 | 191-215 | 230-254 |

| 269-293 | 308-332 | 347-371 | 386-410 | 425-449 | 464-488 |
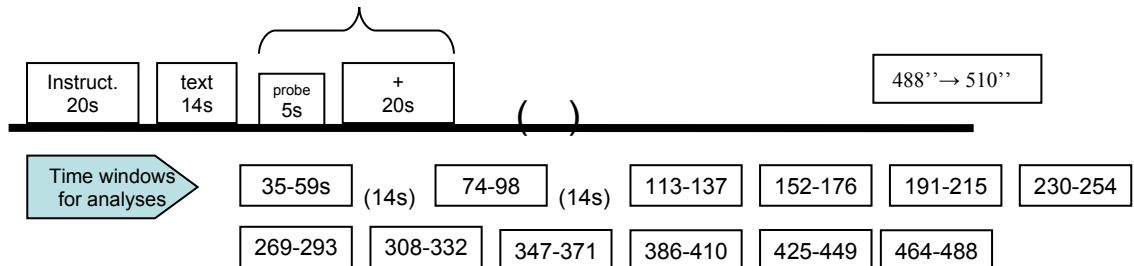
* Conditions: 1st block (B1): Microstructure
           2nd. block (B2): Situational model
           3rd. block (B3): Macrostructure

For the final 5 participants in each group, the order of the 1st and 3rd blocks was inverted.

The first screen displayed the instructions, which remained there for 20 seconds. Next, the whole text was presented on the screen for 14 seconds, followed by the five-second corresponding probe presentation. Twenty seconds of rest period followed, with

a black cross displayed on the center of a white screen. In total, twelve groups of texts and probes were presented per block. The final twenty-second rest period of the first two blocks was followed by a message displayed on the screen to inform the participant it was the end of the block and time for relaxing for some minutes, and at the end of the third block, a message informed the end of the experiment.

3.3 PROCEDURES

When participants came to contribute to the research, they were first of all asked to sign an informed consent which gave them detailed information about the general procedures that would be followed, the nature of the research, the risks or collateral effects (which did not exist, in this type of experiment, except if the participant frequently suffers from migraine, since the plaques may bring some discomfort in this case), the confidentiality of the research, among other information that could be relevant. Elderly and young French-native speakers were paid C$ 25.00, while young English-native speakers were paid C$ 30.00, because their test was longer, since they also had to fill out the questionnaire on data about their proficiency, use and age of acquisition of French, as well as the standard test of French, to confirm their level of proficiency.

Data acquisition for this study was developed in three phases. The first step was the application of a battery of neuropsychological tests, and then both behavioral and imaging data were collected simultaneously, preceded by a practice session to familiarize the participants with the task.

3.3.1 Tests and questionnaire's application

Neuropsychological tests were applied to the participants in order to get information to correlate with the data obtained by behavioral and imaging testing, as well as to measure whether all participants had acceptable patterns of performance within their age and educational level groups, and, thus, could have their data included in the analyses. The application was done in a separate room, next to the lab room, specially reserved by the institute for this aim. Tests were applied in the participants' native language (French for the elderly and young French-native speaker groups, and English for the young English-native speakers group).

The choice of tests also observed the minimal interference of the applicant's accent (this researcher, Brazilian Portuguese native speaker), so that this could not be an intervenient factor to affect results. This session took about forty-five minutes for French speakers and about one hour and fifteen minutes for English speakers, who answered the questionnaire on bilingualism and the proficiency test of French as soon as the neuropsychological tests had been applied.

3.3.2 Practice session

As soon as the equipment was settled on the participants' head (the installation is explained below), a procedure that takes in general fifteen minutes, the practice session started. It consisted of the presentation of three texts, especially designed for the training

part, followed by their corresponding probes. This activity aimed to familiarize the participant with the type of texts and of answers required, as well as for the timing.

The practice session was repeated as many times as the participant required, until s/he felt confident to start the acquisition session.

Before the presentation of the texts and corresponding probes, the participant was asked to read some instructions displayed on the screen. The instructions were presented in French for the French native speakers and in English for the English native speakers. (Appendix D).

As soon as they read it, the researcher gave the same instructions in a more detailed way, orally, to make sure they understood what to do and the sequence and timing of presentation of the task, explaining about the intervals between each block. The researcher explained to them that the information presented in the probe following each text should be judged as plausible or not according to the content of the text, that is, they should judge whether the sentence presented after the text was logic, acceptable, according to the content of the narrative. They were instructed to read the probe, judge its plausibility in relation to the narrative and press the button as fast as possible, within the five-second-time.

Participants were comfortably seated in front of the computer, about 70cm away from the computer screen, and had to press a green key on the keyboard (letter "q") if the sentence was true in relation to the text, or a red key (letter "p") if the sentence was wrong.

When the task had been understood, data acquisition for the practice session started, but the results were not registered, and the NIRS equipment remained deactivated.

3.3.3 Behavioral data acquisition session

As soon as the practice session had been completed, the simultaneous behavioral and imaging data collection started. The researcher counted until three, and at the same time NIRS (monitored by an engineer) and EPrime programs were started and data recording began.

Behavioral data were captured and processed by the EPrime program installed in the computer where the participants developed the task. The program recorded information on accuracy and response time. Moreover, it sent through parallel ports to the NIRS equipment an indication of the initial moment when the participant was expected to answer the task; that is, a sign was sent to the NIRS equipment at the beginning of the presentation of each sentence probe, as soon as the reading of the text finished and the probe was displayed on the screen. This artifact facilitated the further analyses developed by the HoMER program, the statistical tool designed to develop NIRS analyses.

The order of presentation of the task was controlled, so that half of the participants in each group read first the MIC group of texts, followed by the SIT and MAC groups, respectively, while the other half of participants read first the MAC condition texts, followed by the SIT and MIC conditions, respectively. This arrangement

in the sequence of texts' presentation was done to ensure that the order of presentation could not be a factor to influence in the results; that is, in this way, one could not attribute a better result in the final condition due to an artifact produced by the task, namely, getting used to it and acquiring higher automaticity and facility in answering the final block. Moreover, in order to control for the handedness effect, since right-handers tend to be faster in answering with the right hand, keys were changed for the final 5 participants of each group.

Before the beginning of the task, the instructions given in the practice session were repeated and the researcher checked whether there were still some doubts regarding answering the task or any other aspects related to the experiment itself.

3.3.4 NIRS data acquisition session

NIRS data were captured simultaneously to EPrime acquisitions, which recorded the behavioral data on accuracy and response time. NIRS sources and detectors (TechEn CW5 system) were placed on flexible plastic probe holders, which were set bilaterally and attached to the head of the participant with Velcro (see Figure 4, below).

The geometry of the probes, that is, the distribution of the sources of infrared light and detectors, presented in Figure 5, allowed the simultaneous measurement of frontal and temporal regions, including Broca and Wernicke's areas in the LH and their counter-lateral homologous in the RH.

Fig. 4: Participant with NIRS/OI plaques installed for data acquisition
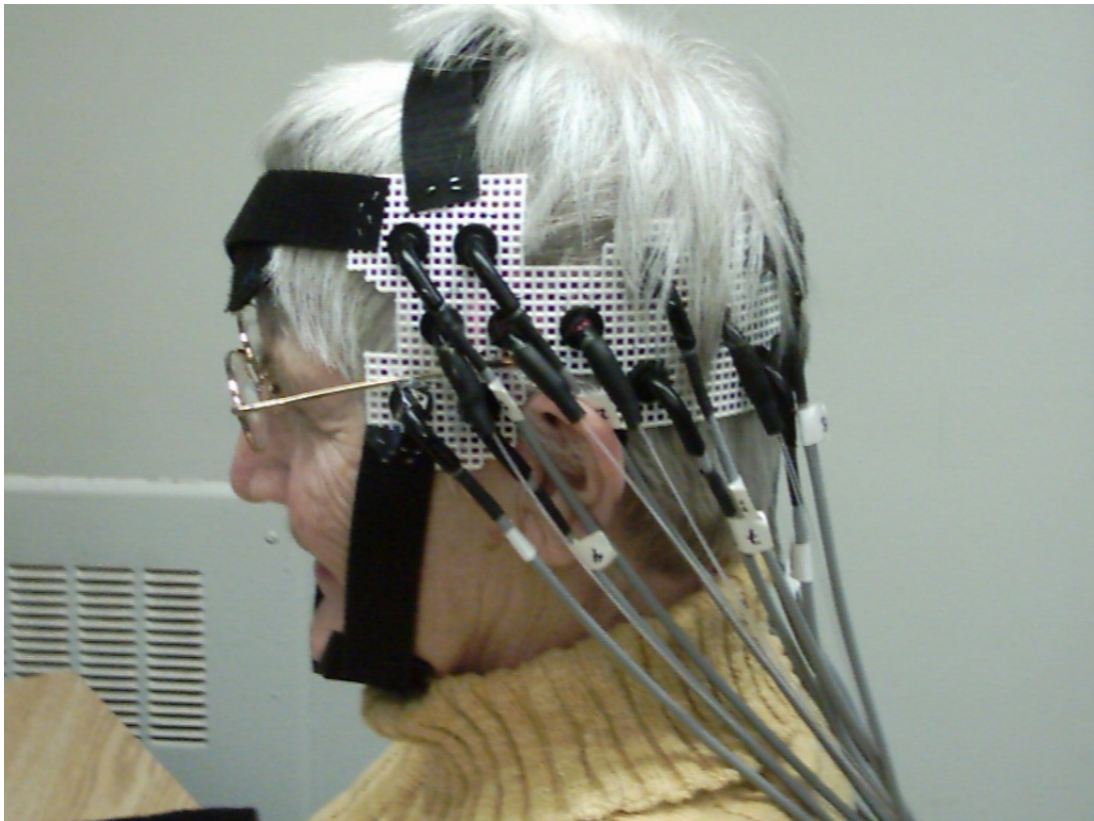
Fig. 5: Arrangement of sources (red) and detectors (blue) placed bilaterally on regions including Broca and Wernicke areas, according to the 10x20 system

RH

LH
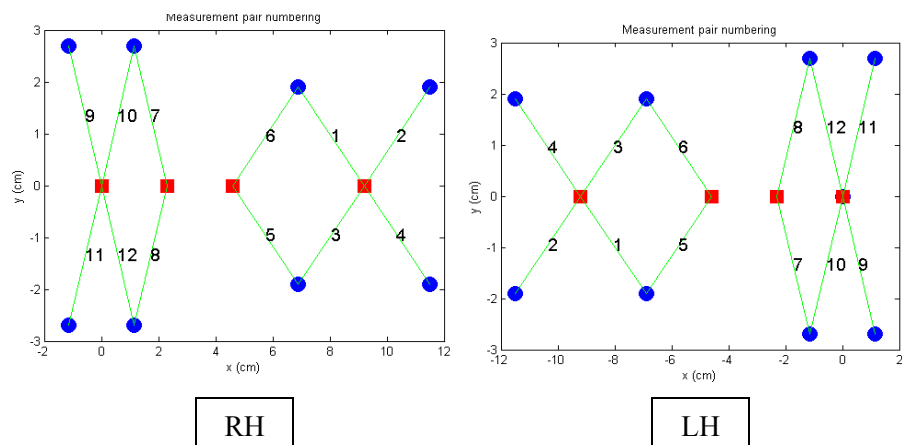
The placing of the optodes was done in accordance with the 10 x 20 System (Jasper, 1958) used for EEG studies (see Figure 6, below), and took as reference the electrodes F7 (LH) and F8 (RH), which were located in between the triangular area formed by the three frontal inferior optodes in the plaques, and T3 (LH) and T4 (RH), which were located approximately in between the third inferior and superior detectors and in between the second and the third sources, bilaterally.

According to the Talairach coordinates for Brodman's area (see Figure 7, below), Broca's region (BA 44 and 45) is located right superiorly to F7 region in the LH and to F8 in its correlate area in the RH, while Wernicke's area (BA 21 and 22) comprises the region just above and to the right, approximately one centimeter, to the electrode T3 in the LH and T4 in its RH counter lateral part.

The procedures for plaques placement in order to ensure the focus on Broca and Wernicke's areas were taken following the procedures adopted by other researchers who investigated the same areas also with NIRS and with ERP (Friederici et al., 1998, Coch et al., 2002).

As NIRS and behavioral data were collected simultaneously, the same task design and instructions for task resolution were adopted for NIRS data acquisition (a full description of task presentation is given below and visually presented in figure 3, above).

Fig. 6: Representation of the 10 x 20 system (Jasper, 1958)
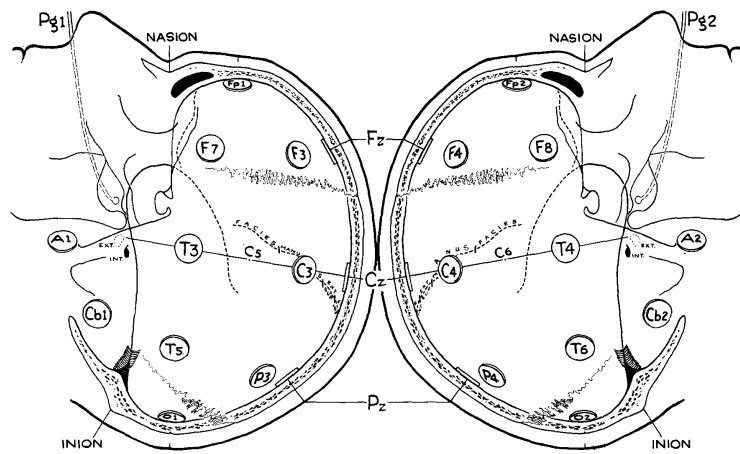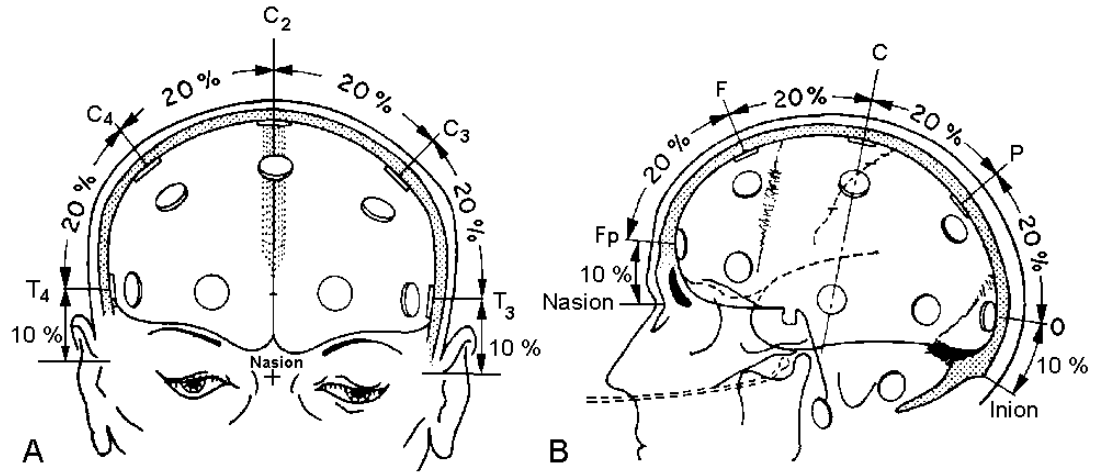
Fig. 7: Brodman's areas
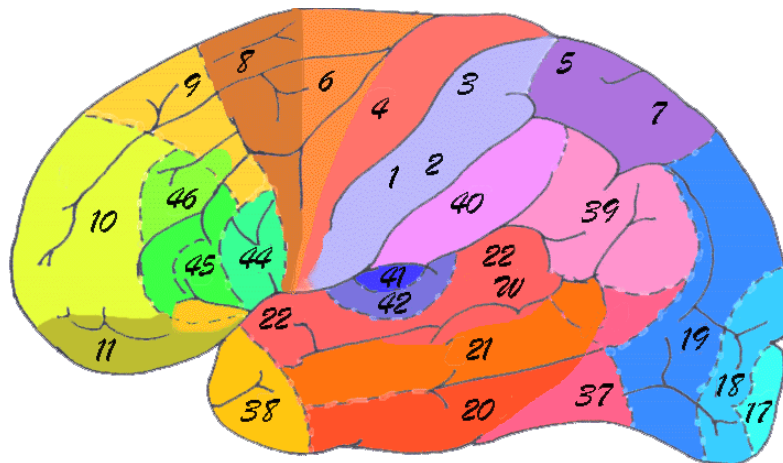
An important instruction related to movement was given to the participants. They were asked to avoid any type of movement during the task; movements would be allowed in the intervals given after each block.

The lights in the room were turned off during the procedure in order to avoid their possible influence on data acquisition. The temperature in the room was always controlled and only 3 people stayed in the room during the acquisitions: the engineer (who controlled the NIRS equipment and equated sign quality), the participant and the researcher. All kinds of noise were avoided, in order to provide a calm, quiet and comfortable environment for data collection.

- *Task presentation for behavioral and imaging data collection*

When the instructions had been understood and the practice session had finished, data acquisition started. Each block began with a period of 20 seconds baseline, when the participants viewed a black cross in the middle of the screen. After that, task presentation started with the first text, fully presented in the middle of the screen for 14 seconds. Then, the probe was displayed for 5 seconds; within this five-second-time, the participants had to read and judge the sentence, by pressing the green key (if the sentence was true by reference to the text) or the red key (if the sentence was false) on a keyboard. After that, a period of 20 seconds followed, in which the participant was asked to look at the black cross in the middle of the screen and continue avoiding movements. Stimuli presentation lasted 488" in each block, but they were programmed

to last 510 seconds, since a time period multiple of 3 is demanded by the NIRS system to organize the data. After the first and the second block were presented there was a rest period, when the participant had one or two minutes to rest, according to his/her necessity. The duration of the task, not including the two rest periods, was of 25.5 minutes.

The procedures for data analyses will be presented in the next sections.

3.4 NEUROPSYCHOLOGICAL TESTS, QUESTIONNAIRE AND PROFICIENCY TEST'S DATA ANALYSIS

Results brought by the neuropsychological tests were evaluated according to their standardized norms for age and schooling categories (when it was the case) and copied to Excel spreadsheets, where the averages per test and per group were calculated.

Data from the questionnaire were calculated with the aid of the SPSS PC version 13.0 program (SPSS, Inc., Chicago, IL) and Excel program. The proficiency test was corrected according to the answers and scale of points which accompany the test, and the average of points was calculated in a scale of 1 to 100.

3.5 BEHAVIORAL DATA ANALYSIS

Analyses were developed on the data from participants who achieved an accuracy level higher than 50%, in order to try to exclude any performance which may have been at chance, since it was a *true or false* task. No data had to be eliminated following this criterion.

Data were sent from the EPrime program to Excel spreadsheets, where the average of response time and accuracy scores per condition and per type (false/true) were calculated.

Individual results for accuracy and RT were copied to another Excel spreadsheet and organized per group (EF, YF and YE), to allow further comparison between the groups of participants and the three conditions.

Due to the number of participants per group and to the fact that the curves resulting from data distribution were not always regular, the Kruskal Wallis test was applied. This nonparametric test resembles the One-way ANOVA test, and was applied to compare the three groups for each condition. Statistic significance was accepted at $p<0.05$. After that, post-hoc comparisons were developed on Excel program to detect where exactly the significant results occurred. Comparisons were made at an alpha level of 5%. Then, the application of the Friedman Two-Way Analysis of Variance by Ranks test verified that the three conditions had been drawn from the same population.

3.6 NIRS DATA ANALYSIS

Data for each participant were analyzed individually and later averaged by group.

First, raw data were filtered to remove artifacts due to cardiac variations and respiration, using a bandpass filter with range 0.02-0.5 Hz. Data were then converted to measurements of oxyhemoglobin (HbO), deoxyhemoglobin (HbR) and total hemoglobin (HbT), according to the modified Beer-Lambert law, arranged into epochs and averaged for each participant at each location. Data filtering and analysis were performed by the HomER (Hemodynamic Evoked Response) data analysis program (developed by the Photon Migration Imaging Lab at the Massachusetts General Hospital in Boston, and Martinos Center for Biomedical Imaging), a graphical interface program used for NIRS data analyses and visualization. The program allows the selection of blocks of time-points or individual channels to be disregarded in analysis allowing for rejection of artifacts such as those described above and of motion. Thus, eventual movements were eliminated from each individual dataset. The HomER program required the use of the MATLab signal processing toolbox (The Math-Works, Inc., Natick, MA).

Substraction was developed by calculating the average of two baseline periods (which were periods in which participants read instructions displayed on the screen), in each individual's data, in each block. The first period to be considered were the first 29 seconds of acquisition in each block (i1); the second baseline was captured after the 12th stimuli of each block, in the final 25 seconds of acquisition (i2). Then, the average baseline was calculated by adding i1 to i2 and dividing the result by two. In a mathematical form: i BASELINE = (i1 + i2)/2.

The next section presents and discusses the data brought by the experiment developed in this study.

CHAPTER 4

RESULTS AND DISCUSSION

This section presents and discusses the data obtained from the various instruments used for data collection: the neuropsychological tests, the questionnaire and the proficiency test, as well as behavioral and imaging data. At the end of the chapter, the hypotheses initially proposed are discussed in accordance with the findings obtained through the experiment.

4.1 NEUROPSYCHOLOGICAL TESTS, QUESTIONNAIRE AND PROFICIENCY TEST RESULTS

As already stated, the *neuropsychological tests* were applied in the study to control for evidences of any attentional, inhibitory or memory problems which could affect the experimental results and thus lead to the exclusion of a participant's behavioral and imaging data. The test battery was evaluated according to the standard norms for each test.

All participants from the three groups were within or above average in terms of their performance in the tests for their age and schooling patterns (when schooling was

considered in the norm for the test). Thus, no one of them exhibited traces of impairment or deficit in short-term working memory (as attested by the Digit Span test), inhibition and attention (as attested by the Trial Making test – Part B and by the Stroop test), working memory for recall (as attested by the Buschke test), or mild cognitive impairment (in the case of aged participants, as attested by the MMSE). Also, in relation to laterality, the scores obtained with the Edinburgh Handedness Inventory revealed that all participants were right-handers. Therefore, data of no one of the participants had to be excluded from the study due to results obtained by the neuropsychological battery applied.

Data obtained from the application of the **questionnaire for bilinguals** have already been shown in the section named "Participants", which presented the profile of the YE group, based on information gathered from the questionnaire.

Like the self-assessment of language abilities in the L2 (French), the application of the standard **proficiency test** (DELF B1 – partie 2, "compréhension des écrits") attested the intermediate level of proficiency in reading in French as an L2 attained by all the participants. As already stated when YE participants were characterized, their average of correct responses was 74.8%, their correct responses ranging from 60% to 88% of the items in the test.

4.2 BEHAVIORAL RESULTS

This section presents the data brought by the behavioral study developed with the aid of the EPrime program, which recorded data simultaneously to NIRS acquisitions. The presentation of the results will be done in two parts, the first depicting the accuracy data, followed by the presentation of the response time data.

As already mentioned in the previous chapter, data recorded by the EPrime program were further analyzed by the Kruskal-Wallis test to compare the groups of participants, followed by a post-hoc analysis by the Friedman test to compare repeated measures for a single participant. Both tests are equivalent to the ANOVA test, in a non-parametric version.

Data on participants' accuracy patterns per condition

The analysis of the histogram (Fig. 8, below) shows an overall higher performance of YF in the three conditions (macro-, micro-structure and situational model). The performance of EF followed the same patterns of YF's performance, although with lower scores (MAC > SIT > MIC).

More specifically, the comparison of accuracy patterns between the three groups of participants with the application of the Kruskal Wallis test revealed no statistically significant differences in the processing of the MIC level ($p = 0,249$). However, statistically significant differences were found in MAC processing between YF and YE* ($p = 0,004$), and in SIT processing between YF and YE* ($p=0,032$).

Figure 8: Graph with behavioral results: participants' accuracy patterns per condition

$p = < 0.05$
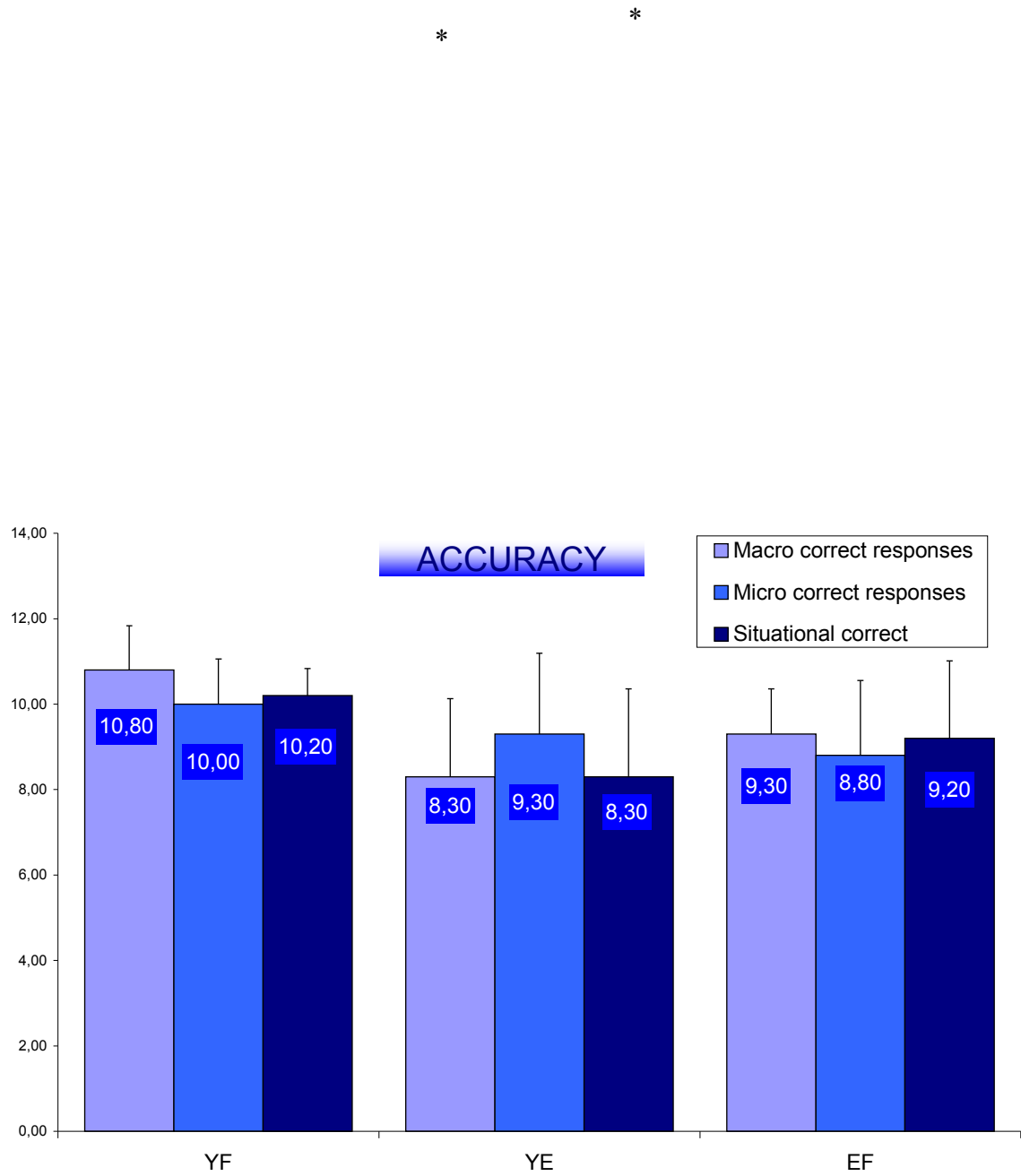
The histogram shows that both groups of native speakers obtained their lowest scores when dealing with the details of the text (micro-structure) in the comparison between the three levels of text processing. Inversely, the YE group, which read the texts presented in their non-proficient L2 language (French), obtained their highest scores remembering details from the text at the micro-structural level, and similar patterns in terms of accuracy when making inferences to understand the macro-structural and the situational levels. The YE group outperformed the EF one in processing the MIC level.

Another aspect to be mentioned regards the standard deviation (SD) patterns, which were lower in the YF performance, as compared to the other two groups. Thus, YF's performance was more homogeneous than the performance of the participants in the other groups. The highest SD patterns were observed in the EF's performance, especially in judging inferences at the situational model, followed by the micro-structure judgments. The results of SD per group and per condition are presented below:

YF = MIC   1,05 > MAC 1,03 > SIT   0,63
YE = SIT   2,06 > MIC 1,89 > MAC 1,83
EF = SIT   1,81 > MIC   1,75 > MAC 1,06

Data on participants' response time (RT) patterns per condition

The group YF was faster in answering the task in the three conditions. Their fastest answers were given to find MIC propositions. In the same way, the group of EF was faster at answering at the MIC level, followed by the MAC and SIT level, respectively. The histogram (Fig. 9, below) shows similar patterns of performance of

these two groups (YF and EF), although the performance of EF reflected an overall higher RT, when compared to YF, but lower RT when compared to YE.

The YE group showed the highest response time when answering the task regarding the MIC level, followed by the MAC and the SIT level, respectively.

Statistical analyses of reaction time considering groups and conditions have shown the presence of significant differences in all three conditions in the comparison of the groups.

For the MAC processing, the Kruskal-Wallis test indicates that there is a statistically significant difference between the groups (p = 0,010) regarding reaction time. Post-hoc comparisons (alpha level of 5%) indicated that YF* differed from YE and that YF* differed from EF.

Fig. 9: Graph with behavioral results: participants' response time (RT) patterns per condition
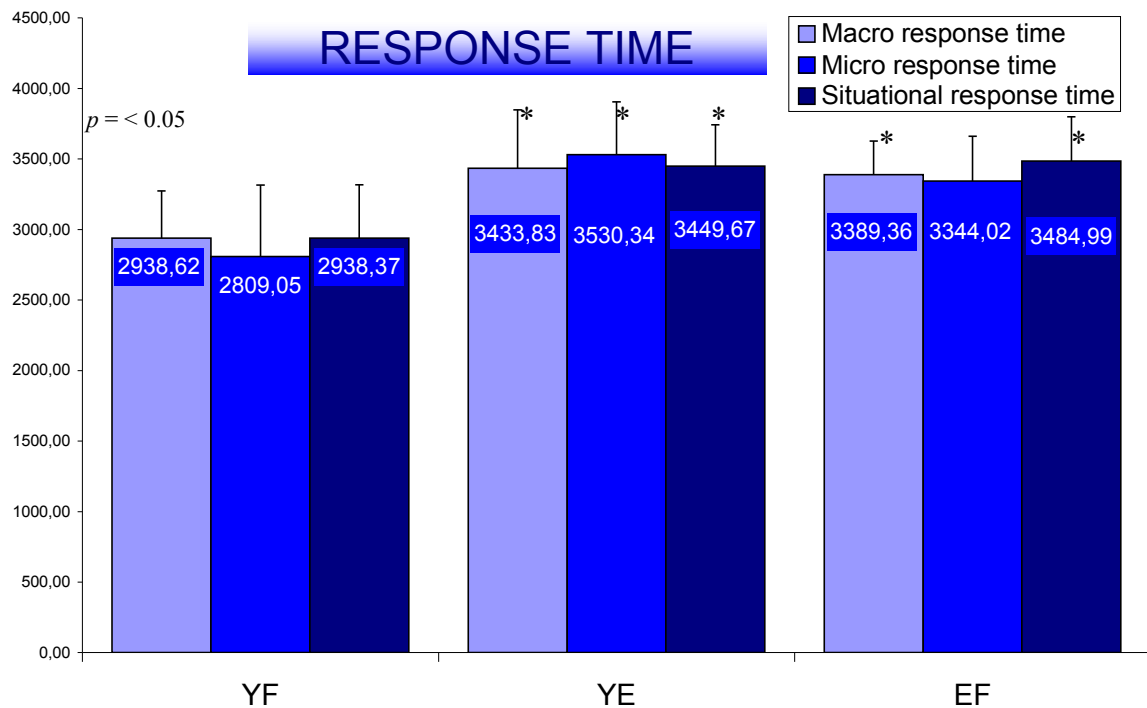
In MIC processing, reaction time significantly differed between YF* and YE ($p =$ 0,009).

There was also statistically significant difference in reaction time in SIT processing ($p = 0,003$). Post-hoc comparison (alpha level of 5%) indicated that YF* differed from YE, and that YF* differed from EF.

4.3 NIRS RESULTS

NIRS data will be presented per group of participants, and after this presentation some general comparisons relating the groups will be drawn.

As an illustration, the average of the concentration of HbO (oxyhemoglobin), HbR (deoxyhemoglobin) and HbT (total hemoglobin) for the ten participants of the elderly French native speakers (EF) group, in macro-propositional level (MAC) processing in the right hemisphere (RH), frontal inferior (FI) region, is displayed in Figure 10.

Individual data of the ten participants in this condition are portrayed in Figure 11. Data of participant number 5 (see Figure 11) were not considered for the analyses and excluded from the study due to movement artifacts during the experiment.

Fig. 10: Sample of a graph with a group average of the concentration of HbO, HbR and HbT: Group EF, MAC processing, RH, FI region
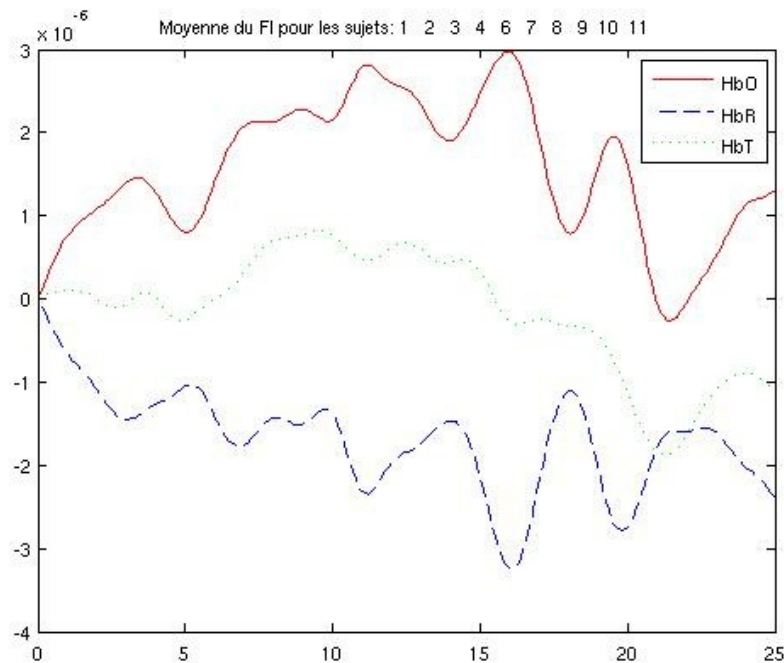
Fig. 11: Sample of graphs with individual data on the concentration of HbO, HbR and HbT: EF Group, MAC processing, RH, FI region
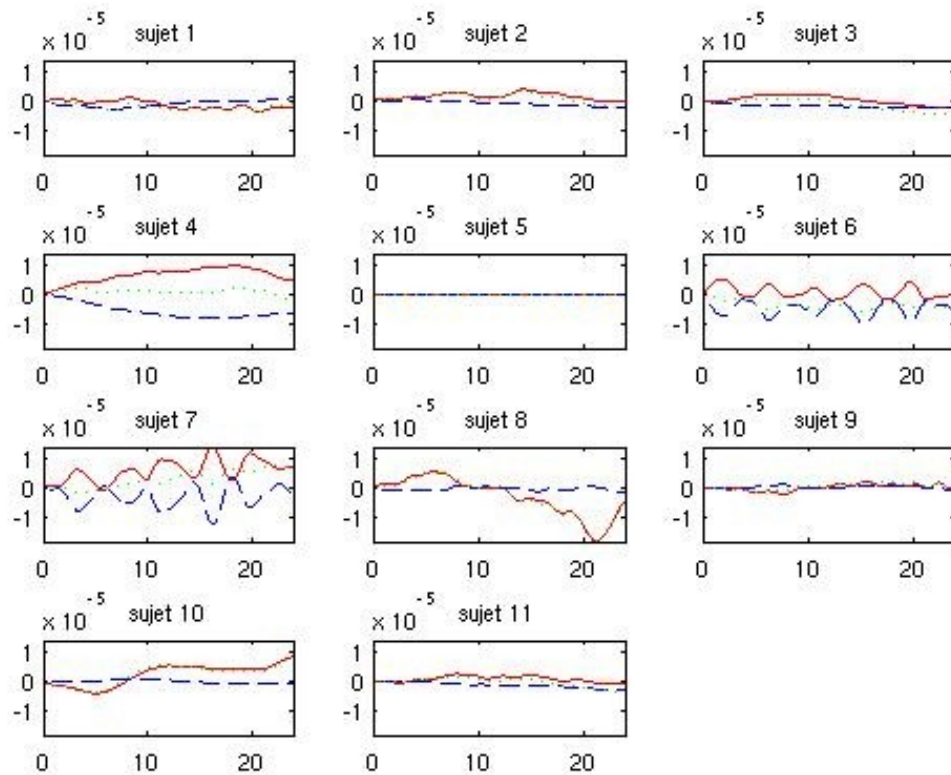
Tables 8, 9 and 10, below, represent the changing patterns of HbO, HbR and HbT, respectively, per condition and regions of interest (ROIs), obtained with young adult French native speakers (YF), elderly adult French native speakers (EF) and young adult English native speakers with intermediate proficiency in French (YE), respectively, and table 11 presents the ANOVA tests to give information about the significance of these changes. Figure 12 illustrates the data presented on table 11, by representing the patterns of activity in each of the ROIs per condition and per group investigated.

Table 8: NIRS data: YF (young French native speakers) per condition and per brain sites within hemispheres   HbO ($p \leq 0.05$) >HbO ($p \leq 0.08$ & ≥ 0.05)   HbR ($p \leq 0.05$) > HbR ($p \leq 0.08$ & ≥ 0.05)

NIRS data: YF, per condition and per brain site within each hemisphere

		LH				RH		
	FS	FI	TS	TI	FS	FI	TS	TI
BLOCK 1 MIC	-0.1703	-0.0662	-0.3761	-0.2458	-0.0170	-0.2404	-0.4657	-0.4629
	0.0161	0.1115	0.1389	0.1099	-0.0547	-0.0162	0.1087	0.1023
	-0.1542	0.0454	-0.2373	-0.1359	-0.0718	-0.2566	-0.3570	-0.3607
BLOCK 2 SIT	-0.3172	-0.2417	-0.3974	-0.3193	0.2306	0.1198	0.1523	0.1752
	-0.0254	0.0245	0.0386	0.0292	0.0316	-0.0059	-0.0291	-0.0114
	-0.3426	-0.2172	-0.3588	-0.2900	0.2621	0.1139	0.1232	0.1639
BLOCK 3 MAC	-0.4623	-0.2579	-0.5252	-0.4450	-0.1294	-0.3116	-0.3488	-0.3728
	0.1472	0.2047	0.2788	0.2514	0.0432	-0.0232	0.0390	0.0502
	-0.3151	-0.0532	-0.2464	-0.1936	-0.0861	-0.3348	-0.3098	-0.3226

(FS= frontal superior; FI = frontal inferior; TS = temporal superior; TI = temporal inferior; the three columns of values correspond, respectively, to the concentration of HbO, HbR and HbT)

Table 9: NIRS data: EF (elderly French native speakers) per condition and per brain sites within hemispheres   HbO ($p \leq 0.05$) >HbO ($p \leq 0.08$ & ≥ 0.05)   HbR ($p \leq 0.05$) > HbR ($p \leq 0.08$ & ≥ 0.05)

NIRS data: EF, per condition and per brain site within each hemisphere

		LH				RH		
	FS	FI	TS	TI	FS	FI	TS	TI
BLOCK 1 MIC	0.0751	0.1832	-0.0701	-0.0625	0.1545	0.2238	-0.0024	0.0033
	-0.0256	-0.0498	0.0123	0.0313	-0.0566	-0.0753	-0.0709	-0.0517
	0.0495	0.1333	-0.0578	-0.0312	0.0979	0.1485	-0.0733	-0.0484
BLOCK 2 SIT	0.0985	0.1414	-0.0796	-0.0948	-0.0094	0.0852	-0.1729	-0.2068
	-0.0303	-0.0479	-0.0095	0.0115	-0.1032	-0.0826	-0.0164	-0.0124
	0.0682	0.0935	-0.0891	-0.0833	-0.1126	0.0026	-0.1893	-0.2192
BLOCK 3 MAC	0.2093	0.2397	0.0000	-0.0170	0.3656	0.4594	0.1632	0.1370
	0.0012	0.0142	0.0217	0.0528	-0.2624	-0.3334	-0.1923	-0.1878
	0.2105	0.2539	0.0217	0.0358	0.1032	0.1260	-0.0291	-0.0508

(FS= frontal superior; FI = frontal inferior; TS = temporal superior; TI = temporal inferior; the three columns of values correspond, respectively, to the concentration of HbO, HbR and HbT)

Table 10: NIRS data: YE (young English native speakers) per condition and per brain sites within hemispheres HbO ($p \le 0.05$) >HbO ($p \le 0.08$ & ≥ 0.05) HbR ($p \le 0.05$) > HbR ($p \le 0.08$ & ≥ 0.05)

NIRS data: YE, per condition and per brain site within each hemisphere								
	LH				RH			
	FS	FI	TS	TI	FS	FI	TS	TI
	0.7640	0.7343	0.6975	0.6748	-0.5181	-0.5875	-0.4632	-0.4734
BLOCK 1	-0.1643	-0.1573	-0.1854	-0.1844	0.1732	0.1009	0.0018	0.0252
MIC	0.5997	0.5769	0.5122	0.4905	-0.3449	-0.4865	-0.4614	-0.4481
	0.1019	0.0015	0.0542	0.0676	-0.3516	-0.2871	-0.3284	-0.4477
BLOCK 2	0.1617	0.2120	0.2179	0.1990	-0.0152	-0.1789	-0.1419	-0.1381
SIT	0.2636	0.2136	0.2721	0.2665	-0.3668	-0.4660	-0.4703	-0.5858
	0.3269	0.4491	0.2410	0.2577	-0.0778	-0.0925	-0.0916	-0.1021
BLOCK 3	0.1768	0.2478	0.2028	0.2045	0.0010	-0.0005	-0.0022	0.0026
MAC	0.5037	0.6968	0.4438	0.4622	-0.0768	-0.0930	-0.0938	-0.0994

(FS= frontal superior; FI = frontal inferior; TS = temporal superior; TI = temporal inferior; the three columns of values correspond, respectively, to the concentration of HbO, HbR and HbT)

Table 11: ANOVAS for determining the significance of blood changing patterns, according to groups of participants, conditions and ROIs.
HbO ($p \le 0.05$) >HbO ($p \le 0.08$ & ≥ 0.05) HbR ($p \le 0.05$) > HbR ($p \le 0.08$ & ≥ 0.05)
HbO ($p \le 0.1$ & ≥ 0.09) HbR ($p \le 0.1$ & ≥ 0.09)

ANOVAS for determining significance of blood changing patterns										
		YF			EF			YE		
		MIC	SIT	MAC	MIC	SIT	MAC	MIC	SIT	MAC
LH	FS	0.3453	0.2682	0.2107	0.5229	0.4622	0.2366	0.0012	0.8328	0.6888
	FI	0.3908	0.3434	0.3712	0.0784	0.2933	0.1619	0.0007	0.5164	0.5862
	TS	0.0078	0.1028	0.1226	0.5783	0.6490	0.8974	0.0018	0.5990	0.9145
	TI	0.0724	0.1949	0.1816	0.5689	0.5465	0.6945	0.0034	0.6698	0.8902
RH	FS	0.9217	0.4502	0.6190	0.1815	0.7620	0.0670	0.0865	0.4051	0.1339
	FI	0.5748	0.6624	0.3770	0.0961	0.5889	0.0215	0.1362	0.7241	0.0837
	TS	0.1251	0.4946	0.2143	0.7415	0.6205	0.3006	0.1652	0.5903	0.0510
	TI	0.1419	0.5046	0.1910	0.7690	0.5612	0.3453	0.1642	0.3739	0.0219

Fig. 12: **Representation of patterns of blood changes in ROIs per group and condition**
⬆ **= HbO (oxygenation)**   ⬇ **= HbR (deoxygenation)**

🔴 **(*p* ≤ 0.05)**   🟣 **(*p* ≤ 0.08 & ≥0.05)**   🟡 **(*p* ≤ 0.1 & ≥0.09)**

Patterns of blood changes (ROIs x conditions x participants)
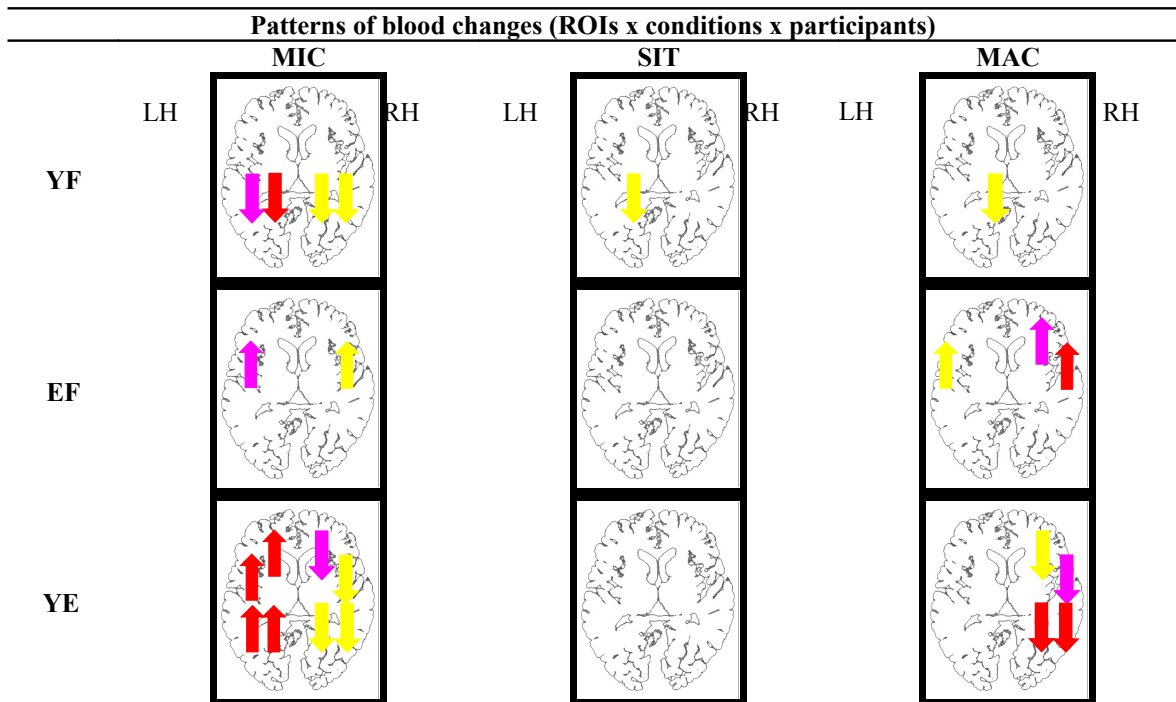
* YF group (young adults, French native speakers)

An analysis of tables 8 and 11 shows that, for the group YF, overall, there occurred several inverted curves, in which there was an important decrease in levels of oxygenation in different areas, in both hemispheres. The statistically most important decrease in oxygenation levels occurred in the TS region in the LH in MIC level processing, followed by the TI in the same hemisphere, for the same condition.

MIC level processing determined modifications in blood volume by generating an increase in HbR in frontal regions (FS and FI), bilaterally. A statistically significant inverted curve (that is, considerable increase in HbR) occurred in the TS area in the LH,

as already stated; the same pattern was registered in the TI region in the same hemisphere, although not as significantly as in the TS area.

SIT level processing led to a bilateral increase in HbR, in all sites (frontal and temporal ROIs), mainly in the LH, especially in the TS region, but not in a statistically significant way.

Finally, MAC level comprehension revealed the occurrence of inverted curves, with high levels of HbR in both hemispheres. There was a tendency for a more important participation of temporal areas, bilaterally, as compared to frontal regions.

Group EF (elderly adults, French native speakers)

Data from Tables 9 and 11 reveal a tendency among participants to activate the FI region in the LH while processing MIC level. The comprehension of this level revealed statistically non-significant patterns of activation (increase in HbO) in the frontal areas bilaterally (mainly in FI regions) and HbR increase in temporal areas.

SIT level showed no statistically significant changing patterns of blood volume in any ROI among the EF group in average. Inverted curves (increase in HbR levels) were the main pattern observed, while some increase in HbO levels was registered in frontal areas, bilaterally (in FS and FI in the LH, and in FI in the RH).

Processing of the MAC level data revealed a significant activation (increase of HbO) in the FI area in the RH in EF group, the same pattern being observed in the FS area in the same hemisphere, although with lower statistical significance. Patterns of blood volume changes suggest a tendency to activation in the two frontal areas in the LH as

well, although no statistically significant differences were achieved when participants' data were averaged as a group.

Overall, there seemed to have occurred more significant changing patterns of blood volume in frontal regions, mainly in the RH, than in temporal regions. Moreover, data suggest a tendency of higher levels of HbO in frontal areas, bilaterally, and of HbR in temporal areas, especially in the LH.

Another important aspect to be mentioned is the occurrence of a great heterogeneity in the data brought by this group as compared to YE and YF groups. In other words, the highest inter-subject variability was registered in this group of participants, which could be observed in their curves of oxygenation and deoxygenation patterns in the different conditions.

Group YE (young adults, English native speakers)

An analysis comparing Tables 10 and Table 11 indicates a very significant activation (HbO increase) in all ROIs in the LH (FI > FS > TS > TI) for MIC level processing. In the RH, an important tendency to the occurrence of inverted curves (HbR increase) was registered in the four ROIs, much more prominently in the FS area, although none with statistical significance.

No statistically significant changes in blood volume were observed in SIT level processing. Inverted curves (that is, a reduction in the levels of HbO) were seen in the RH while the opposite pattern (increase in HbO) was observed in the LH, similarly to what has been seen in MIC processing by this group of participants.

MAC level data processing showed a significant changing pattern of blood volume in the RH in TI and TS regions, more significantly in the TI area. Frontal areas in the RH, mainly the FI region, showed changing blood patterns (increase of HbR levels), with no statistical significance, though. There was an increase in HbR and a decrease in HbO in the four ROIs of the RH at MAC level processing.

An overall analysis of the data brought by the YE group points to the existence of different patterns of blood changes in both hemispheres: while there seemed to have occurred higher levels of HbO in the LH, in the RH an increase in HbR levels seemed to have been the case.

Finally, a recurrent pattern observed in blood changes in this group (YE) was a tendency to a delay of some milliseconds as compared to the data of the other two groups.

Taken together, the data brought by the three groups of participants suggest the occurrence of general different patterns of oxygenation in discourse processing among the groups. YF showed the greatest amount of inverted curves (a prominent reduction in HbO levels) in both hemispheres, as compared to EF and YE. In EF processing, there was a tendency for higher levels of HbO in frontal lobes and of HbR in temporal lobes, bilaterally. Yet in discourse processing by YE, HbO seemed to have been more recurrent in the LH, while HbR levels have been more observed in the RH.

All sites in the temporal and frontal areas under investigation in this study have revealed statistically significant participation (HbO augmentation) in the MIC condition processing, in the LH, by YE participants.

Finally, another aspect to be mentioned is that SIT processing caused no statistically significant changes in a specific ROI as compared to the other regions in the groups investigated.

The discussion of the data presented above and of the one originated from the behavioral part of the experiment will be correlated in the next section to findings brought by the literature, presented in the second chapter.

4.4 DISCUSSION

This section has been organized in the following way: first, behavioral data brought by the three groups of participants regarding accuracy and response time patterns are discussed, supported by the literature reviewed in the second chapter. Then, data brought by the NIRS experiment are discussed in the same way, with a special emphasis on the role of the right and left hemispheres in processing the task. Following, the findings will be related to the relevant literature in the area. The section then finishes by presenting a discussion of the hypotheses which had been proposed.

Regarding the ***behavioral data***, more specifically, the *accuracy performance* of the three groups under investigation, the analyses of the data show a greater facility of the YF group in answering the task in the three levels of textual structure, according to their results in the accuracy levels. In the comparison between elderly and young readers presented in the literature, this has been the case in some studies, which indicated an overall better performance of young adults in relation to older adults, whose text

comprehension may be harmed due to their difficulty in detecting the relevance of a piece of information and/or in making proper inferences (Radvansky, 1999; Radvansky et al., 2001). The lowest scores obtained by non-proficient readers were expected, due to their low proficiency in the language.

Some studies, such as the one developed by Stine-Morrow et al. (1996), have reported an advantage of younger adults' performance at the micro-structural level in relation to older adults, due to their better memory for surface aspects of the text. This has been the case in this study, where both groups of young participants outperformed the elderly one at the MIC level, although not in a statistically significant way. However, the higher scores in the MIC processing by YE participants in relation to EF's scores may also have resulted from the fact that the interpretation of the text level may be simpler, easier for low-proficient readers as compared to higher order levels of text interpretation (MAC and SIT). The micro-structure of the text is text-based (Kintsch, 1988), that is, its information is given in the text, not demanding the construction of extra intra-textual (within the text) or inter-textual inferences (relating information from different previous "texts" to one the reader is exposed to). Thus, problems with coping with the target language due to a reduced proficiency may have posed difficulty for the interpretation of the higher levels of the texts, which may not have been the case for the micro-propositional level. Differently from what was observed in the study developed by Chen and Donin (1997), the limited language proficiency affected more the higher order level processing than lower one.

Both YE and (mainly) EF presented the highest standard deviation patterns for SIT, MIC and MAC, respectively. Possibly, in the case of YE, their reduced level of

proficiency has posed some difficulties for an easy interpretation of the text, originating a higher divergence in responses and lower levels of accuracy. Conversely, in the case of EF, it has been reported that, although elderly participants may sometimes perform better than younger ones at the situational and macro-propositional levels, they may have more difficulties in choosing an appropriate inference from among those let available in their minds, probably due to inhibitory control deficits related to aging (Hasher & Zacks, 1988; Beeman, 1998), which would lead to higher response times and reduced accuracy at the situational level as compared to their younger pairs (YF).

Both French speaking groups (YF and EF) have shown higher scores at the MAC level, followed by the SIT and the MIC level, respectively. This result is in line with Kintsch's (1998) theory, which poses that the macro-structural aspects can easily be depicted from the text as soon as the micro-structure has been computed. The author postulates the idea of the existence of only two instead of three basic text levels – the micro-structural and the situational one – being the macro-propositional level naturally understood as a consequence of a good micro-structural comprehension. Comprehension at the situational level, however, relies on extra-textual knowledge, that is, on world knowledge, acquired from the exposure to other visually or orally presented "texts", that is, from inter-textual pieces of information to which one has been previously exposed (Kintsch & van Dijk, 1988). Thus, this may explain why more mistakes have been made by these two groups at the situational than at the macro-propositional level.

As for *response time data*, similarly to what was found in the accuracy levels, overall, the YF group presented overall lower response time than the elderly adults group (EF), corroborating what has been reported in the literature (Stine-Morrow et al.,

1996, 2001; Ska & Joanette, 2006). The patterns of response time were similar for both French speaking groups (EF and YF), with both reflecting the lowest response time in responding at the micro-propositional level. This result suggests that micro-propositions, text-based pieces of information, can be faster retrieved from the content of the text by native speakers, since they do not demand extra types of inferences, as already mentioned. Low-proficient L2 speakers revealed a higher response time in processing the MIC level, followed by the MAC and the SIT level. Their higher response time was in the type of processing in which they also obtained their higher level of accuracy. A possible explanation for this would be the use of a strategy of devoting more time for a type of processing in which they may have considered themselves more able to answer, since it represents the least complex task among the three proposed.

Imaging data obtained in this study aimed to contribute with evidences to explore how the brain regions under investigation (frontal areas surrounding Broca's region and perisylvian regions comprising Wernicke's area) participate in the process of comprehending narratives in their different levels (MIC, MAC and SIT levels).

NIRS technique provides information on changes on HbO (oxy-hemoglobin), HbR (deoxy-hemoglobin) and HbT (total hemoglobin) while participants perform a task. Since it is still a very recent technique, the nature of these hemodynamic patterns has continuously been analyzed. In fMRI, the blood oxygen level-dependent (BOLD) signal is taken as an indicative of brain activity. This signal captures HbR changes, similarly to what is obtained by investigations using NIRS. With the use of NIRS, researchers also have information of HbO levels, which have been considered by the majority of them as representing evidences for brain activation rather than the HbR levels. It seems

reasonable to ascertain, though, that a significant increase in one or other type of hemodynamic pattern may indicate brain activity in a determined area, since both may represent an evidence of oxygen consumption for the performance of a task. Thus, at this stage, more conclusive answers about the nature of these two types of patterns are being sought for. In the research here presented, some differences in these patterns could be depicted, which may lead to different presuppositions or reflections on how to explain what HbO and HbR changes may represent during language (and discourse) processing:

1 Is there a tendency for HbO increase in frontal areas for demanding tasks? In the statistically significant hemodynamic changes in the frontal areas, bilaterally, an increase in HbO has been observed during YE and EF's performances, except for a tendency of HbR increase in YE participants in the frontal RH. Considering the unquestionable higher demands imposed on YE participants to cope with reading in a non-proficient L2 and the probable higher difficulties of EF in performing the task, as suggested in the literature, the answer for this question could be yes, since statistically significant levels of HbO were registered in frontal regions while YE processed the narratives, mainly in the LH. As for the elderly participants, a wider recruitment of frontal areas and a statistically significant increase of activation, observed in this experiment, has already been reported in the literature (the HAROLD phenomenon, by Cabeza (2002) and others), explained as representing a possible attempt of the brain to compensate for deficits generated by aging. Thus, more empirical evidences should be brought to verify whether there is a tendency for higher HbO levels in frontal areas for language processing by populations with reduced ability in performing the task, and, if this is the case, the reasons why this happens (if linked to inner speech produced as a

rehearsal or extra aid for processing, being this rehearsal linked to Broca's articulatory area (Buchweitz, 2006); if caused by physiological characteristics of temporal areas, which would impose difficulties for imaging techniques to detect activity in these regions, among other possible causes).

2 Are higher levels of HbR rather than of HbO registered in less demanding or more automatized computations? In the YF group, there was a great predominance of HbR volume in all ROIs, bilaterally, statistically significant in the TS area in the LH for MIC processing, and in TI, LH, in a more reduced concentration. One may speculate, then, that increase in HbR levels captured by NIRS may be related to an "affordable" level of difficulty in coping with a task since the analysis of behavioral data showed the highest levels of accuracy and the lowest response times for this group while answering all the tasks. However, this assumption must be further investigated since, in this same experiment, significant levels of HbR, and not of HbO, were registered in YE comprehension of the MAC level, which may have imposed difficulties for processing, as justifiable for their lower score in this task.

The relevant participation of the RH for MAC processing in EF and YE

NIRS data brought by this investigation have shown an important participation of the RH in discourse processing, especially in the construction of the macro-structure of the text, corroborating findings brought by previous studies, which have pointed to the prominent participation of the RH, mainly of frontal areas, in tasks demanding the construction of story representations (Gernsbacher & Kaschak, 2003). Hough (1990) has also pointed to the role of the RH in integrating information in a coherent and holistic

manner. Corroborating this assumption, Beeman and colleagues (2000) and Federmeyer and Kutas (1999) postulate the role of the RH in drawing inferences during story comprehension as well as in the establishment of global coherence, facilitated by the ability of the RH in coarse coding, that is, in letting available a high variety of possible meanings to be chosen from. Finally, St. George and colleagues associated the participation of middle temporal regions, mainly in the RH, to integrative processes for global coherence[7].

In the study here reported, statistically significant hemodynamic changing patterns were observed in RH frontal areas (in the elderly group and, also in a relevant way, in YE participants) and in RH temporal areas (in the YE group). These statistically significant changes in blood volume patterns in the RH were only observed in the YE and EF participants' macro-propositional processing, while no statistical difference was observed in YF's processing of this same level in the right nor in the left hemisphere. The nature of the participation of the RH varied among these two groups (YE and EF), though, in two ways:

1 Firstly, the type of blood pattern differed: while in EF there was an increase in HbO, in YE the increase was in HbR levels. As already discussed, no conclusive answers have been found yet about the nature of these two signals. However, statistical changes in both these patterns may represent evidence for brain activity in the areas where they are captured.

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[7] It is known that the hippocampus, a temporal region, is responsible for maintaining coherence of incoming information during text reading, thus an important locus for memory processes. However, NIRS technique does not have yet the power to investigate cerebral structures located so deep in the brain, only cortical regions on brain surface, with a depth varying from two to three centimeters.

2 Secondly, the activation in EF occurred in the frontal lobes, while in YE it was more significant in temporal areas. Explanations for the recruitment of different areas by these populations can be found in the literature. In the case of EF, as stated above, higher levels of activation in frontal areas and extra recruitment within these areas are recurrent hemodynamic patterns in aging, probably as a compensatory mechanism to cope with emerging cognitive and functional declines, such as in attentional and WM resources. As for YE, although it has been stated in the literature that MAC processing is linked to RH frontal areas, bilinguals with a low or intermediate proficiency in their L2 represent a distinguished group, and thus other variables have to be considered when analyzing their data. The important but non-statistically significant FI increase in HbR volume in the RH and the statistically important RH temporal increase of HbR during MAC processing by YE in this study may be explained by the way knowledge of the non-proficient language is stored, that is, to the organization of bilinguals' memory system. Pragmatic and metalinguistic knowledge stored in the declarative memory play an important role in L2 processing. These types of knowledge may recruit mesial temporal lobes and parahippocampal structures bilaterally (Paradis, 1997), which may be recruited for MAC processing by non-proficient bilinguals, as confirmed by the RH temporal activation observed in this study. Researchers such as Perani (1998), Dehaene (1997) and Fabbro (2001) have corroborated the assumption of a wider dispersion of brain circuitry in processing of a weaker L2 as compared to L1 processing, and they postulate that this variability may represent compensatory strategies to deal with the L2. Yet, one may also consider the fact that the low-proficiency bilinguals in this study are late bilinguals, that is, acquired the L2 after the age of nine. Late acquisition is associated by some

researchers to a wider and sometimes more right-lateralized brain circuitry as compared to the processing of an L1 (Vaid & Hull, 2002, among others).

The role of the LH in discourse processing

Statistically significant hemodynamic changes were not observed in the LH during the construction of higher-order text levels, namely at the MAC and SIT levels of the narratives, by any of the three groups of participants. However, at the comprehension of the text-based level the LH was significantly recruited. The LH showed statistically significant hemodynamic changes during MIC processing by YE and YF, respectively, and prominent activation in EF's processing, although not as importantly as in the other two groups in terms of statistics. Statistically significant changes were expressed by a HbR increase in YF's MIC processing and by a HBO increase in EF and in YE' performance at this level.

The supportive role of the LH in text comprehension, especially in a more textual basis, has already been postulated by some researchers (Tomitch et al, submitted; Tomitch et al., 2004; Beeman et al., 2000). Due to its specialization in searching vocabulary in a more focal, narrow way (Waldie & Mosley, 2000), the LH plays an important role in semantic processing at the micro-propositional level (Gernsbacher & Kaschak, 2003). In this study, a very significant activation of the LH, in frontal and temporal areas, was observed in YE participants, which may be explained by the demands for dealing with focal vocabulary in the text. Their more demanding reading process as compared to YF may have required the mobilization of a wider and increased

LH region (even including FS area in the RH) to reach text comprehension at the micro-structural level.

To summarize, some comparisons among the groups of participants can be drawn considering MIC processing in the LH:

a) Similarity among the three groups: MIC processing by the three groups generated significant hemodynamic changes in the LH.

b) Divergences among the three groups:

* While in YE and EF the changes were in HbO levels, in YF they were in HbR levels. As already stated, conclusive explanations on the nature of these two different hemodynamic patterns have not been achieved yet; however, as both represent changes in hemodynamic responses, they may indicate activity in the specific brain region where they emerge.

* While in YE and EF the frontal regions were the most activated ones, mainly the FI (although not in a statistically significant way in EF), in YF the temporal regions were significantly involved, mainly the TS. Vocabulary is partially supported by procedural knowledge (in terms of the automaticity of its syntactic features – linked to the frontal region) and at least partially by declarative knowledge (in terms of the concepts evoked by the words – linked to temporal region). Thus, a possible explanation for the recruitment of different areas within the LH could be that YF tried to integrate the word level information into the mental representation of the text, in a more holistic way, while EF and YE remained in textual bases, by paying more attention to the words themselves, in a decontextualized way, relying on the more "fine coding" role of the LH in dealing with word meanings (Beeman, 1998). Another possible explanation for the

recruitment of a wide area within the LH for MIC processing refers to the way the text was encoded: possibly, encoding was better done by YF and propositions had already been sent to declarative memory (in temporal lobes), while in EF and YE a greater reliance in WM (a function developed mainly in frontal areas) was chosen to find text-based information. Yet, another possibility is that frontal activation may have been an effect of rehearsal through inner speech as a strategy to help to evoke memories from the text just read.

* *Understanding discourse processing in aging and in L2 low proficiency: a theoretical approach based on converging evidences*

A great amount of behavioral and imaging studies with different techniques have already been implemented, but the understanding of the cerebral dynamics in language comprehension and production is still far from being fully understood. Some theories have emerged aiming to explain these processes, as discussed in the literature review presented in Chapter 2. The discussion that follows aims to interpret the evidence brought by this study, in terms of the inter- and intra-hemispheric interplay in the discourse task investigated, in the light of two theoretical frameworks: the Hemispheric Asymmetry Reduction in Old Adults (HAROLD) Model and the Banich Model.

Two potential populations to bring some crucial information on the biological bases of language processing have been the scope of this study: bilinguals, whose complex language system(s), impaired or not, represent(s) a window for the brain circuitry in language organization and processing, and elderly individuals, whose aging

brain allows us to interpret the interplay between brain sites and cognitive functions, such as memory, attention and inhibition.

As already mentioned in the literature review here presented, the aging brain seems to suffer some changes in the way cognitive tasks are approached, probably in order to compensate for deficits which emerge in aging and to maintain the same or similar performance as young adults reflect (Ska & Joanette, 2006, Kramer et al., 2006, among others).

The aging brain undergoes some losses in its structure, which are more important in frontal areas (Head et al., 2004). Recurrent patterns stated in the literature, and already mentioned in this dissertation, are 1) an increased and more diffuse frontal activation in older as compared to younger adults in tasks requiring effortful retrieval and/or source judgments (Cabeza et al, 2002; Li et al., 2004), and 2) the recruitment of extra areas, often bilaterally, by older adults to perform dual tasks or tasks imposing a heavy load on WM capacity (Smith et al., 2001; Reuter-Lorentz et al, 2000). According to the Hemispheric Asymmetry Reduction in Old Adults (HAROLD) Model, frontal activity tends to be less lateralized in older than in younger adults while performing a cognitive task (Dolcos et al., 2002, Cabeza, 2002 and Cabeza et al, 2004, among others). This process, named by Cabeza as "dedifferentiation", suggests that, in the aging brain, other areas, in general the hemispheric counterparts, are activated when performing cognitive tasks, probably as a compensatory mechanism or as a difficulty in recruiting specialized neural mechanisms. In this way, activities that used to be an attribution of a determined area tend to be shared by other regions, frequently in the hemispheric counterpart.

In this study, elderly participants activated a large area in the RH frontal region - the FI in a statistically significant manner, and the FS also in a relevant way (see tables 9 and 11) – for processing MAC level, while no significant changes were observed in these areas in the young adults, French native speakers. Rather, in YF, there was a tendency for HbR increase, an opposite pattern of what has been observed in EF's performance, whose task resolution generated significant increase in HbO levels. The fact of no significant changes in hemodynamic patterns having been observed in YF's performance suggests an automatic and effortless achievement of the construction of this higher level of text comprehension by this group, which is the case, as stated by Kintsch (1998), when the textual information easily permits the elaboration of inferences necessary for macro-structure construction. According to the analysis of the behavioral data, EF had more difficulty than younger adults (YF), although not in a statistically significant way, to achieve the construction of the MAC of the narratives, which could explain the high activation of frontal regions in the RH. Their lower scores in MAC processing (as well as in the other two levels) as compared to YF may be the result of a reduced ability to inhibit irrelevant information and to select the most appropriate inference among all the possible ones which one may consider (Beeman, 1998; Radvansky, 1999).

An analysis of the homologue areas to the RH frontal regions in MAC processing has revealed no statistically significant changes in the hemodynamic response. However, a tendency of an increase in HbO levels in the FI region in the LH, the same region which was highly activated in the RH, has been registered, as shown in Tables 9 and 11, while a tendency of HbR increase can be observed in temporal areas.

The same tendency to counterpart activation has been registered in MIC processing, when the FI region activation in the LH (more actively recruited) has also been observed in the RH counterpart, although not in a statistically significant way when the data were averaged within the group. Thus, the involvement of the hemispheric counter-part is in accordance with an assumption of the HAROLD Model regarding the dedifferentiation in terms of brain activity in cognitive functioning in aging.

Another aspect that may corroborate the assumptions postulated by the model is the fact that the most heterogeneous signals captured by NIRS were brought by the EF group, as observed in the changing patterns of HbO and HbR curves (for an example, see Figure 11), followed by the YE's performance. This heterogeneity may reflect the involvement of different or extra areas from those recruited by younger adults (YF), and/or different levels of activation within the areas recruited by each group. The recruitment of wider and non-specialized areas may lead to a reduction in performance, which was the case in this experiment. In the case of YE participants' performance, it may as well mean strategy choices, since the strategies to learn a second language may not be the same within a bilingual group.

One may ask, though, why these patterns have been observed in MAC processing and not in SIT processing by older adults, considering that the comprehension of the SIT level might be an even more complex task for older adults. Two possible explanations may be given to this finding. First, as proposed by the HAROLD Model, frontal areas, in high-performing older adults, may reflect the highest changes in activation, by being more active when solving cognitive tasks as compared to younger adults' performance. Since MAC processing is strongly related to frontal areas in the RH, this would be the

most affected and demanded site by elderly readers for solving a reading task at the MAC level. The second explanation relates to the nature of SIT model processing. For building the SIT model, the reader needs to link the incoming information of the text, which is maintained in WM (an attribute strongly related to the frontal lobes) to extra-textual information, related to world knowledge, already stored in memory (an attribute strongly related to temporal areas, among others). Thus, the computation of the SIT model takes place in a wider brain network, comprising frontal and temporal areas (among others, not investigated in this study), differently from MAC processing, mainly in the RH frontal area. The changing hemodynamic patterns in this distributed network may have become non-significant, and, therefore, not considered in the NIRS statistical analysis. To corroborate this possible answer, one may consider the fact that the SIT model processing has not led to significant changes in any hemisphere for any group of participants, not even for the YE group, whose low scores in this task reflect their difficulty, and probably high demands in brain activity, to cope with the task.

To sum up, from the discussion presented so far, it is plausible to suggest that the data brought by this study indicate the occurrence of a wider and significant activation of RH frontal areas for the construction of the macro-structure of a narrative by elderly individuals as compared to younger adults' performance in the same task, being this activation observable, in a less significant way, in the FI area in the LH counterpart. Thus, these results seem to corroborate the assumptions brought by the HAROLD Model.

A second discussion to be developed refers to the patterns of hemodynamic changes during YE participants' performance and the theoretical framework which could explain them.

As stated in the literature reviewed in this dissertation, the processing of a low-proficient L2 recruits a wider circuitry in the brain, accompanied by more significant hemodynamic changes in determined sites, as compared to native language or proficient L2 processing (Perani et al, 1996, 1998; Dehaene et al, 1997, Vaid & Hull, 2002, among others). In low L2 proficiency, these changes involve the RH to a greater extent than in a proficient L2 or in native language processing. One explanation for higher RH involvement would be a greater reliance of low-proficient bilinguals on pragmatics and on declarative memory, which would be linked to the RH. Thus, if one cerebral region does not have the automatic and explicit knowledge necessary to solve a linguistic task, a compensatory mechanism activates RH areas to look for pragmatic information which could help cope with the task.

In discourse processing by this group, the highest statistically significant patterns of brain activity have been observed, along with the highest amount of sites activated, in both hemispheres.

The recruitment by YE participants of extra areas and the increase in hemodynamic activity in determined regions as compared to YF's processing may be explained by the Banich Model. As already discussed in Chapter 2 in the literature review, this model assumes that, whenever there is an increase in task difficulty, extra areas are recruited, some times the counter-lateral areas, and/or there is an increase of activation in the involved area(s) aiming to cope with the difficulty.

Thus, the assumptions proposed by this model seem to fit as a reasonable explanation for the patterns of brain activity observed in YE's inter-hemispheric dynamics, since the participants' difficulties posed by their limited knowledge of French, confirmed by their behavioral data and proficiency test, may have imposed an extra effort to cope with the task.

Going further and linking the data analyses drawn from both elderly and bilingual participants, one may assume that the same theory applicable to low proficient L2 readers may be applicable to elderly participants. In the comparison established between these two groups, some converging evidence and similar patterns have been observed, leading us to presuppose that, although the nature of the difficulties in the two groups is different (in one group, deficits in language processing may emerge due to aging, while in the other, due to L2 low proficiency), the mechanisms found by the brain to compensate for them and overcome deficits are similar (that is, increasing hemodynamic responses and/or extra recruitment of brain areas, sometimes the counterlateral regions).

Thus, one may postulate the idea that the Banich Model would embrace the HAROLD Model, which is specifically applicable to an aging population, and that it would serve as a good way of interpreting data when researchers investigate the effect of a reduced or harmed ability in performing a cognitive task, as well as the effect of task complexity in different populations.

To conclude the discussion here developed, the hypotheses raised at the onset of the study will be now analyzed in the light of the data obtained. They will be presented

according to the population they address (bilinguals and elderly individuals) and to the type of data (behavioral and imaging).

Hypotheses concerning behavioral results:

a) For elderly participants' processing:

HYPOTHESIS 1: Regarding accuracy, it is expected that, when compared to young participants (YF), aged participants (EF) will show lowered performance at processing micro-propositional level (MIC), whereas they will show similar performance when processing macro-propositions (MAC) and the situational (SIT) model. More specifically, it is expected that <u>older participants</u> will have <u>lower scores at their micro-propositional analysis</u> as compared to the younger participants' scores, but similar scores in relation to MAC and SIT processing.

The hypothesis was not confirmed. Elderly participants had lower scores in MIC processing as compared to YF's scores, however the difference in performance did not reach statistical significance. Comparing the data to what has been reported in previous studies, as already mentioned, in which younger adults outperformed elderly ones in comprehending the MIC level of texts, data brought by this study partially corroborates this finding, since no statistical significance was obtained, although a tendency to this difference has been found.

HYPOTHESIS 2: Elderly participants (EF) will show <u>higher response times in average for the three conditions</u> when compared to the group of young French speakers (YF).

This hypothesis was partially confirmed. Elderly participants revealed higher response times to solve the task in the three levels of comprehension as compared to YF. However, the differences in response time between these two groups were statistically significant for MAC and SIT processing, but not for MIC processing. This finding - higher response times for processing higher textual levels - may have reflected elderly participants' tendency to have difficulties in choosing among possible inferences the one which would best suit, as discussed in the literature review. This was especially the case at SIT level processing.

b) For lower proficiency level participants' processing:

HYPOTHESIS 3: Non-proficient young adults, English native speakers (YE), will show lowered performance, that is, more incorrect responses in the three conditions as compared to young French native speakers' performance; their scores will be lower at processing MAC and SIT levels than at MIC processing.

As expected, accuracy levels were lower for YE's comprehension of the narratives in the three levels, due to their intermediate level of proficiency in French.

The hypothesis was confirmed. There were statistically significant differences in the performance of YF and YE at MAC and SIT levels processing, but not at MIC level comprehension.

Corroborating findings reported in the literature, which suggest more facility for young adults in comprehending and remembering text-based information, higher levels of accuracy were attained by them in the MIC level. Another possible explanation for YE's better performance at the MIC level is that text-based information may have been more easily processed by them then higher textual orders, whose comprehension may be more affected by a lower proficiency level.

HYPOTHESIS 4: Non-proficient young bilinguals (YE) will show higher response times for all the three levels of L2 text processing as compared to young French native speakers' performance.

The hypothesis was confirmed. Statistical differences in response times in all the three conditions were found between YF and YE while answering the task. This was expected because of YE participants' intermediate proficiency level in French, which demanded extra time and effort for reading comprehension.

Hypotheses concerning imaging results:

a) For elderly participants' processing:

HYPOTHESIS 5: Increased and more diffuse loci of activation in both hemispheres is expected in aged participants (EF) in all three levels; more specifically, it is expected that the SIT and MAC analyses will reflect higher frontal activation, especially in the RH, as compared to younger adults French speakers, and that bilateral activation in older adults is expected for MIC processing.

The hypothesis was partially confirmed. Bilateral activation was reflected in the FI region for MIC processing (higher in LH than in RH, but not in a significant level) and also in the FI region for MAC processing (statistically significant activation in the RH and lower in the LH). However, only MAC (and not SIT) level processing reflected higher frontal activation as compared to YF participants' patterns of activation. In fact, SIT processing did not recruit brain regions in a statistically significant way in these two groups of participants.

b) For lower proficiency level participants' processing:

HYPOTHESIS 6: An increased and more diffuse loci of activation in both hemispheres is expected in non-proficient participants (YE), very pronounced in the RH as compared to the young adults native-language speakers, in all three levels of text processing, especially in MAC and SIT levels; more specifically, it is expected that all levels of analyses will involve increased activation and more diffuse temporal and frontal sites of activation, detectable with NIRS, and that the diffusion and activation will be higher in the RH in non-proficient participants' performance.

This hypothesis was partially confirmed. Only MAC processing (and not SIT) significantly recruited RH areas; MIC processing was pronouncedly processed in the LH, with the contribution of the FS area in the RH, although not in a significant way. In accordance with the hypothesis formulated, the hemodynamic changes were significantly increased and in more diffused areas as compared to YF's processing.

CHAPTER 5

CONCLUSIONS, LIMITATIONS OF THE STUDY, SUGGESTIONS FOR

FURTHER RESEARCH AND FINAL REMARKS

In this chapter, final conclusions will be drawn from the discussions developed in this dissertation concerning discourse processing by elderly adults and non-proficient bilinguals, based on the findings brought by the experiment and the relevant literature in the area. Moreover, this final section will present some of the limitations of the study, followed by some propositions of further investigations which could be conducted from this one and which could contribute by providing complementary data. Finally, some final considerations will be made regarding the study developed.

5.1 CONCLUSIONS

The results of the studies having looked at discourse processing by elderly adults and non-proficient L2 speakers have shown higher levels of accuracy in the three text levels (MIC, MAC and SIT) in young French native-speakers adults (YF) as compared to elderly French native-speakers adults (EF) and young non-proficient bilinguals, English native-speakers adults (YE). Both groups of young adults outperformed elderly ones in processing MIC level, corroborating findings brought by the literature. In the

case of non-proficient bilinguals, higher scores as compared to elderly adults' ones may as well be attributed to a strategy choice, since higher response times (RT) were also registered by this group at the MIC level, which may indicate a higher application of resources for processing this level.

Behavioral results show overall comparable patterns in accuracy and RT between YF and EF (the native-speakers groups) considering the text levels (that is, higher accuracy in MAC, SIT and MIC, respectively, and lower response time in MIC level processing), with the elderly group showing overall lower accuracy and higher response times, although with no statistically significant differences.

The differences found among the groups in terms of behavioral and imaging data can not be attributed to impairments or deficiencies of working or short-term memory, or attentional or inhibitory control, since all participants showed normal to high scores in the neuropsychological tests applied, according to the norms of the tests for their age and educational level groups.

Neuroimaging findings brought by this study provided much evidence for our understanding of the inter- and intra-hemispheric dynamics in discourse processing of visually presented narratives, allowing us to compare brain areas' recruitment in the three levels of discourse processing, by analyzing the hemodynamic changes of oxyhemoglobin (HbO) and desoxyhemoglobin (HbR) using NIRS (Near-Infrared Spectroscopy).

The patterns of hemodynamic changes have revealed an important participation of the LH in MIC processing, pointing to the relevant contribution of this cerebral hemisphere for the computation of text-level information. This may be the case due to

the recruitment of the LH for focal semantic processing for word retrieval (versus coarse coding semantic processing attributed to the RH), as indicated in the literature and probably to syntactic and semantic computations at the sentence level. The frontal inferior region was the main area recruited by both elderly native-speakers and non-proficient bilinguals, suggesting the involvement of this area in lower-level of text computations. Elderly participants did not recruit brain regions in a significant way to cope with MIC level processing, and had the lowest scores in terms of accuracy at this level in the comparison with the other groups. This may be explained by a deficient resource allocation to cope with a difficult task, as measured by their behavioral data, similarly to what has been suggested by some previous studies.

Right hemisphere participation was more prominent in EF and YE participants, mainly at the MAC level comprehension. In the case of the EF group, MAC processing demanded the most significant activation, in frontal areas of the RH, as compared to the other conditions. A possible explanation for this important recruitment may be elderly participants' difficulty in drawing inferences due to their tendency to a more deficient inhibitory control as compared to younger adults' capacity, as mentioned in the literature on discourse processing in aging. Yet in the case of the non-proficient bilinguals' group, a higher RH activation may reflect their attempt to cope with their lack of proficiency in the L2, by searching for pragmatic clues for their non-automatized control of the language.

The comparison of the hemodynamic changes among the three groups seems to distinguish certain patterns: EF reflected higher recruitment of frontal areas, bilaterally, than of temporal ones, and it was marked by being of oxygenation rather than

deoxygenation, differently from YF, whose performance generated the occurrence of higher levels of deoxygenation. Yet YE performance revealed oxygenation patterns in the LH and deoxygenation ones in the RH. The real nature of these changing patterns has still to be elucidated by further research, since NIRS studies are very recent.

The main aim of this study was to analyze the underlying inter-hemispheric dynamics during discourse processing by elderly adults and non-proficient bilinguals, considering the three textual levels (micro-, macro-structure and situational level), in order to investigate the nature of this dynamics. Two teories which try to explain this nature have been considered, namely the Hemispheric Asymmetry Reduction in Older Adults (HAROLD) Model (Cabeza, 2002), for cognitive processes in the aging brain circuitry, and the Banich theory (Banich & Weissman, 2000), which focus on hemispheric cooperation regarding task demands.

The analyses of the hemispheric activity during discourse comprehension by the two populations here investigated (elderly adults and non-proficient bilinguals) bring evidence which corroborate both theories.

In the case of elderly participants' performance in the discourse task, significant activation was registered in the frontal RH, more pronouncedly in the frontal inferior region, mainly at the macro-propositional level. According to the HAROLD Model, higher recruitment of frontal areas, especially in the RH, is expected. Moreover, the data seem to point to a cooperation of the homologous area in the counter-lateral hemisphere in the case of MIC and MAC processing, suggesting the possible participation of the hemispheric counter-part to cope with the task and maintain levels of performance similar to those of younger adults' ones.

Considering young adults non-proficient L2 speakers, the Banich theory would predict an inter- and intra-hemispheric cooperation to cope with difficult tasks. Reading in a non-proficient L2 imposed a higher level of complexity to the bilinguals as compared to young adults native speakers. Evidence brought from the experiment revealed a significantly more extended and higher recruitment of areas responsible for task processing (frontal and temporal LH areas in MIC processing and temporal RH areas in MAC processing), as predicted by the model. Moreover, a tendency to the counter-lateral hemisphere homologous areas' participation in the processing of MIC level has been noticed, as revealed by the statistical analyses developed, thus illustrating another aspect postulated by the theory, namely the inter-hemispheric cooperation for demanding tasks.

Taken together, data brought by the analyses of the performance of these two populations suggest the occurrence of similar patterns of inter and intra-hemispheric participation, leading us to consider the idea that, at least to a certain extent, similar issues may underlie their performance in discourse processing (and probably extendable to other linguistic computations). In other words, the hemispheric dynamics may be explained by the cognitive demands imposed by a task, that is, the more demanding the task is, more the brain recruits the participation of a widespread network, sometimes including homologous areas in the counter-lateral hemisphere.

Although the biological nature of the older adults and non-proficient bilinguals' brains differ to a certain extent, the task could be considered to be more demanding for both groups – for the bilinguals, due to the low proficiency in the L2, while for the aged group, due to the nature of the discourse task (which represents a complex computation),

since higher resource allocation seems to be needed by older adults to maintain similar patterns of performance to those obtained by younger adults. Moreover, strategy choices adopted by elderly participants and non-proficient bilinguals may also have played a role in trying to maintain comparable performance levels to those attained by young adults native-speakers.

Thus, the Banich framework could be considered as a plausible explanation for the performance of both groups investigated in this study, by postulating a theory which may embrace both patterns of performance. In both populations, the higher level of task difficulty as compared to its processing by young-adult-native speaker group may explain the patterns of brain inter- and intra-hemispheric participation in processing the different levels of discourse. If this was to be the case, then further studies should be done in order to better understand the inter-hemispheric dynamics underlying communication in the healthy aging individuals as requiring supplementary cognitive resources allocated to language abilities. In this case, this would mean that the elderly individual is able to maintain language performance, but with a cost in terms of resources. In this context, it could be predicted that any small loss of brain efficiency in the elderly would have larger impact than the same loss occurring in a younger adult.

Finally, it is important to point to the use of NIRS as a reliable and promising neuroimaging technique for the study of language processing in the brain. This convivial technique may contribute to enlarge our understanding of discourse processing in special, since its more ecological validity as compared to other imaging techniques provides a special environment to the investigation of brain circuitry in this still recently explored research field.

5.2 LIMITATIONS OF THE STUDY

The most important limitation of the study was the complexity of neuroimaging acquisition and analyses, due to the recency of NIRS studies in language tasks, which provided us few comparable studies. The fact that NIRS is a very innovative and promising neuroimaging technique qualified the study here presented, but, at the same time, it imposed a longer period for its implementation and analyses, since a deep study of the literature on NIRS experiments had to be done by the research team involved in this study. Initially, the proper optodes positioning for the experiment had to be especially analyzed and performed; following, task design demanded an accurate testing, due to the nature of the study, which dealt with discourse processing, with no comparable study having been developed by that time. Besides, this study was the first carried out at the Centre de Recherche Institut Universitaire de Gériatrie de Montréal (CRIUGM). For these reasons, experiment design and data analyses demanded doubled caution and effort to ensure its quality.

5.3 SUGGESTIONS FOR FURTHER RESEARCH

As an extension of the study here developed, it would be interesting to try to replicate the findings by means of the use of another imaging technique, such as fMRI. This would bring enrichment to this study, by allowing comparisons between the data from both studies if the conditions and variables controlled for were the same.

Data could also be further investigated by analyzing within-group differences; that is, in the bilingual group here studied, qualitative analyses could be performed by relating subgroups' performance in terms of a possible correlation between different ages of L2 acquisition and frequency of L2 use at home to their imaging and behavioral data.

Also, considering only the elderly participants' performance, an analysis of their behavioral results in relation to their scores in the neuropsychological tests should be developed, to verify if there are some correlations between schooling, working memory and reading comprehension in the three textual levels. It would be advisable to expand the number of participants to obtain more statistical power.

The study could be replicated in its actual format, but with the inclusion of a condition which would impose higher difficulty in processing, in order to investigate the effect of increased task complexity in hemodynamic changes. Then, one could bring more evidence to confirm the applicability of the theoretical approaches here suggested for data analyses.

Other ways of going beyond this experiment would be testing other populations. For instance, a study could analyze the hemispheric dynamics to take place while highly proficient bilinguals process discourse, to replicate studies with this population which have shown similar patterns of activation as those presented by native speakers in other linguistic tasks, such as word and sentence processing, but have not been fully investigated at the discourse level processing. Still, discourse processing by elderly participants in a more advanced age, such as from 70 to 80, could be investigated, since the most prominent cognitive changes, when comparing younger to older adults, have

been perceived from 70 years on. Finally, the study could investigate how brain-damaged (young and/or elderly) adults would process the three levels of discourse under investigation in this research, which would contribute to our understanding of the role of the hemispheres in discourse processing.

5.4 FINAL REMARKS

The research presented in this dissertation intended to contribute to a better understanding of the cerebral dynamics which occurs when intermediate-proficiency bilinguals and elderly individuals process narratives in their micro-, macro-structural and situational levels. To achieve this goal, an emergent and promising neuroimaging technique – NIRS – was applied, which seems to suit this type of study, especially due to its ecological validity.

The findings brought by the study suggest the possibility of the application of similar theoretical approaches to explain language processing in these two populations. Although emerging from different reasons (aging or low proficiency in the L2), the deficits brought to language comprehension generate some comparable changing patterns in brain hemodynamics (for instance that of more relevant, wider and sometimes bilateral hemodynamic changes), which could be explained within the same theoretical framework, proposed by Banich and colleagues.

The assumptions here proposed for interpreting the hemispheric dynamics for discourse processing in aging and in low proficiency in a second language should be

further investigated, by the implementation of comparable studies, in order to enrich this debate. Studies should especially be replicated by investigating visually presented texts, since the majority of the investigations of discourse processing has analyzed comprehension of the auditory or oral production mode. Moreover, studies should focus on bilinguals' discourse processing, a population which represents the majority, not the exception, of the world population.

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APPENDIX A
DELF B1 (Partie 2 : " Compréhension des écrits")

■

Partie 2

COMPRÉHENSION DES ÉCRITS

25 points

■

■ Exercice 1

10 points

Avec un(e) ami(e), vous souhaitez suivre un cours de français langue étrangère en France pendant 4 semaines dans le but de vous préparer à l'examen du DALF.
Vous voulez un cours intensif et vous préférez que le cours ne dépasse pas 15 étudiants par classe. Par ailleurs, vous désirez loger en famille, faire des excursions dans des lieux connus, goûter aux spécialités gastronomiques locales, rencontrer des habitants de la région et surtout multiplier les occasions de parler français. Vous hésitez entre les deux organismes suivants :

	Centre de langue de Saint-Rémy de Provence	Centre de Linguistique de Carnac
Programme pédagogique	Français général : 15, 21, 23 ou 30 heures de cours par semaine. 13 niveaux au minimum, garantis toute l'année. Nombre moyen d'étudiants par classe : 8 à 12. Préparation au DELF, au DALF et au diplôme de langue de l'Alliance Française. Tous les examens, sauf le DALF se passent au Centre.	Pratique de la langue : —cours intensifs mensuels (4 semaines et plus) ; —cours semi intensifs semestriels (13 semaines) ; —cours collectifs sur mesure. Préparation au DELF et au DALF Effectifs par classe inférieurs à 13.
Hébergement	Au choix, en internat sur le campus (demi-pension ou pension complète) ou en externat (studio meublé).	Plusieurs formules : dans une famille française ; en résidence universitaire ; en studio indépendant ; dans un centre de séjour ; dans un foyer de jeunes travailleurs (de 16 à 25 ans) ; en hôtels de tourisme.
Activités culturelles	Dégustation de produits locaux dans les restaurants des environs et les fermes provençales. Visite de villages provençaux. Sur le campus : bibliothèque, « cyberdrome » (salle Internet), cinémathèque, gymnase, terrains de sport, foyer-bar.	Rencontres et sorties sportives ; excursions à Paris et dans les châteaux de la Loire ; spectacles ; ateliers hebdomadaires : musique, théâtre, danse, chant, vidéoclub, etc. Le célèbre « Tour du monde en 80 plats » : découverte des cuisines du monde préparées par les stagiaires.
Vivre avec les Français	Club « échange-langue » (échange d'heures de conversation avec des Français), « Points Accueil Plus » dans les boutiques et les restaurants, possibilité de rejoindre des clubs sportifs de la région.	Stages spécifiques orientés sur l'interculturel ; des activités extra-pédagogiques très variées permettant d'aller à la rencontre des habitants de la ville et de la région : soirées, sorties et week-ends en village, échanges, participation à des projets.

Pour chacun des centres de langue, et pour chacun des critères proposés, mettez une croix (X) dans la case « convient » ou « ne convient pas ».

	Centre de langue de Saint-Rémy de Provence		Centre de Linguistique de Carnac	
	Convient	Ne convient pas	Convient	Ne convient pas
Cours intensif / Nombre d'étudiants				
Préparation au DALF				
Hébergement				
Spécialités gastronomiques locales				
Rencontres avec des habitants				

■ Exercice 2

15 points

Lisez le texte ci-dessous, puis répondez aux questions, en cochant (☒) la bonne réponse, ou en écrivant l'information demandée.

Une lueur d'espoir

Sauver les enfants

S'appuyant sur divers traités et textes internationaux, dont la Convention relative aux droits de l'enfant, de nombreuses associations et ONG se mobilisent tous les jours dans le monde pour que diminue le nombre d'enfants enrôlés* dans des groupes armés. C'est le cas de la « Coalition pour interdire l'utilisation d'enfants-soldats », association mondiale créée en 1998 et animée par le HRW (Human Rights Watch). C'est le cas également de nombreuses ONG qui, dans des dizaines de pays, viennent en aide aux enfants-soldats, assurant leur protection et leur garantissant, quand c'est possible, un suivi médical et une scolarisation. C'est le cas surtout du Fonds des Nations unies pour l'enfance (Unicef).
Pression auprès des États, campagnes de sensibilisation. Grâce aux actions concertées de ces organisations, des milliers d'enfants sont chaque année tirés des griffes* de la violence et de la guerre. En févier 2001, l'Unicef a ainsi coordonné la démobilisation de plus de 2500 enfants âgés de 8 à 18 ans qui servaient dans les rangs de l'Armée de libération des peuples du Soudan (SPLA) dans le sud de ce pays, en les acheminant dans des camps de transit. Les responsables de l'Unicef ont assuré que cette action serait poursuivie en 2002 afin de soustraire tous les enfants-soldats du SPLA (environ 10 000) à l'enfer des conflits. Entre mai et novembre 2001, une campagne analogue* menée au Sierra Leone, a permis de libérer quelque 2900 enfants. De la même façon, le gouvernement de la République du Congo (RDC) s'est engagé, en mai 2002, à démobiliser des milliers d'enfants servant dans son armée. En juillet 2001, des équipes issues de diverses associations ont donc pu organiser des tournées dans les casernes de ce pays pour répertorier le nombre des enfants-soldats et préparer leur réintégration dans la société.

Textes et traités

Jusqu'ici, les traités internationaux sur les droits des enfants stipulaient qu'un mineur de moins de 15 ans ne pouvait être enrôlé dans un groupe armé étatique. Certains pays occidentaux mobilisent toujours dans leurs armées, et en toute légalité, des jeunes volontaires de moins de 18 ans. Certains d'entre eux sont morts dans des guerres récentes. Mais de nombreuses voix se sont élevées depuis 10 ans pour ramener l'âge minimum de cet enrôlement à 18 ans. En mai 2000, un « Protocole facultatif » à la Convention relative aux droits de l'enfant a été adopté par l'Assemblée générale des Nations unies. Ce texte invite les États à prendre « toutes les mesures possibles dans la pratique pour veiller à ce que les membres de leurs forces armées qui n'ont pas atteint l'âge de 18 ans ne participent pas directement aux hostilités » (Art.1). Fin 2001, 87 pays avaient signé ce protocole et 10 l'avaient ratifié*, ratification qui a permis à ce texte d'entrer en vigueur le 12 février 2002 (…).

Dossier écrit par Olivier Piot, Les Clés, n°485, 9/15 mai 2002.

* *enrôlé : engagé*
* *analogue : identique*
* *tiré des griffes de : arraché à*
* *ratifié : accepté officiellement*

> À lire :
Rapport mondial sur les droits de l'enfant, HRW, 2002.
La situation des enfants dans le monde, Unicef, rapport 2002.
Allah n'est pas obligé, de Kourouma Ahmadou, éditions Le Seuil.
La guerre, enfants admis, collection GRIP, éditions Complexe.

> Sur le Web :
Human Rights Watch :
www.hrw.org
Unicef : www.unicef.asso.fr

> Lexique :
ONG (organisation non gouvernementale) : association privée à but non lucratif, engagée dans des actions de défense de la société civile ou de la nature au niveau national et/ou international.
ONU (organisation des Nations unies) : créée en 1945, elle compte 189 États membres. Son but est de maintenir la paix et la sécurité internationales, de coopérer au développement économique et social de tous les peuples et de veiller au respect des droits de l'homme et des libertés fondamentales.
Démobilisation : action de rendre à la vie civile (des troupes mobilisées).

1. Ce document a pour but de :   1 point
   - ☐   dénoncer les horreurs de la guerre.
   - ☐   informer sur les actions pour les droits de l'enfant.
   - ☐   faire signer un texte pour les droits de l'enfant.

2. Citez :   6 points
   a) le nom d'une structure qui lutte pour la disparition des enfants soldats.

   _____

   b) trois formes de soutien proposées aux enfants soldats par les ONG.

   - _____

   - _____

   - _____

   c) deux moyens d'action utilisés par les associations auprès des pays et des gouvernements.

   - _____

   - _____

3. Cochez la bonne réponse :   3 points

• La mission de juillet 2001 au Congo avait pour objectif :
   - ☐   d'identifier et compter les enfants soldats.
   - ☐   d'organiser le retour des enfants soldats à la vie civile.
   - ☐   les deux.

• Dans certains pays occidentaux, l'enrôlement des moins de 18 ans est :
   - ☐   possible.
   - ☐   obligatoire.
   - ☐   interdit.

• Le « Protocole facultatif » propose :
   - ☐   d'interdire l'enrôlement avant 18 ans.
   - ☐   d'interdire la participation aux combats avant 18 ans.
   - ☐   les deux.

4. Écrivez l'information demandée :   2 points
   a) Combien d'enfants sont membres du SPLA ? _____

   b) Quel livre A. Kourouma a-t-il écrit sur le sujet ? _____

5. Dites si les affirmations suivantes sont vraies ou fausses en cochant la case correspondante et citez les
   passages du texte qui justifient votre choix.   3 points

• Par la coopération, les ONG obtiennent des résultats positifs.   ☐ Vrai   ☐ Faux

   Justification : _____

   _____

• La majorité des pays membres de l'ONU ont signé le protocole facultatif.   ☐ Vrai   ☐ Faux

   Justification : _____

   _____

APPENDIX B

Questionnaire for bilinguals

Name: Age :   Gender : ( ) Male ( ) Female   Date/hour:
Level of education (Please tick the highest or the one you are attending at present):
( ) elementary   ( ) high school   ( ) college   ( ) university   ( ) master's   ( ) doctoral
Native language: _____ Country where you came from: _____

1 Do you consider yourself fluent in French? (A person can be considered to be fluent if s/he is able to talk with a native speaker without having to consciously translate to his/her native language).
( ) Yes   ( ) No

2 Are you comfortable having an informal conversation with an unfamiliar person (eg, a salesperson or stranger) in French? ( ) Always   ( ) Generally   ( ) Sometimes   ( ) Rarely   ( ) Never

3 Do you think people understand you well when you speak in French? (   ) Yes ( ) Generally (   ) No
How would you classify the presence of accent of your first language when speaking in the second?
( ) Heavy   ( ) Discrete   ( ) Inexistent

4 Please list below all the languages you speak in the order you began to acquire them. Indicate at what age you began to learn each and at what age (approximately) you mastered each (reached native or native-like competence for that age):

language	age began to learn it	age mastered it (if)
a) _____	_____	_____
b) _____	_____	_____
c) _____	_____	_____
d) _____	_____	_____

5 In what setting did you acquire French (e.g., at home, through school, living abroad in a French speaking place…?
_____

6 What is/are the language(s) of:
a) your mother? _____ father? _____
b) your primary caretaker, guardian (if applicable)? _____

7 Please rate your proficiency in your languages on a scale of 1 to 5 (1=excellent; 2=very good; 3=good; 4= regular; 5=poor)

Language	Speaking	Understanding speech	Reading	Writing
_____	___	___	___	___
_____	___	___	___	___
_____	___	___	___	___
_____	___	___	___	___

8 Did you learn French before coming to Canada? ( ) No ( )Yes. If positive, where did you learn it?
( ) at school for _____ (period: specify months or years)   ( ) at work for _____ (period)
( ) at home   ( ) other: _____

9 Have you ever lived in another place/country where you were exposed to French?
( ) No   ( ) Yes   If positive, how long did you live there? _____
Where did you use French there: ( ) at school   ( ) at work   ( ) at home   ( ) you didn't use much French, you spoke mainly in your native language

10 <u>Previous language use</u>: During your lifetime, have you ever (check all that apply and complete the information requested)
___ experienced a time when you used <u>only French</u> regularly? If positive, how old were you? _____
And how long did you use it? _____
___ used <u>both languages</u> regularly but used them in <u>different settings</u> throughout the day (e.g., home x school, home x work,...) If positive, how old were you? _____ And how long did it happen? _____
___ used <u>both languages</u> regularly in the <u>same setting</u> (i.e., used both languages at home or used both languages with friends, etc.) If positive, how old were you? _____ And how long did it happen? _____

11 <u>Current language use</u> : Do you **now** :
___ use primarily one language? If so, which one? _____
___ use both languages regularly but in different settings (e.g., one at home and one at school/ work, one with friends and one with family, etc.)
___ use both languages every day within the same setting (e.g., use both at home)

12 How old were you when you arrived in Canada? _____

13 How long have you been exposed to French in a more intensive way? _____ (specify if the period refers to years or months)

14 <u>Formal instruction in French</u>: Have you had an educational period in French (e.g., school, university)?
( ) No ( ) Yes If positive, how long did it take? _____ (specify period in months or years) Which level was it? ( ) elementary ( ) high school   ( ) college   ( ) university ( ) other: _____
Do you still receive formal education in French? ( ) No ( ) Yes

15 Are you presently attending classes in a **language course** in French? ( ) no   ( ) yes   If positive, specify how many days _____ and hours _____ per week.

16 How many **hours** per day, **in average**, do you spend doing the following activities **in French**?
  a)   watching TV (including the news, videos, movies,…)?   _____hours
  b)   reading (magazines, books, newspapers,…)?   _____hours
  c)   listening to the radio (French news programs, songs…)?   _____hours
  d)   talking to friends?   _____hours
  d)   talking to a French speaking boy/girlfriend, husband/wife? _____hours
  e)   talking to people at work?   _____hours

17 Indicate in the list below the factor(s) that led/lead you to learn French. Please make a double tick at the option(s) that you consider to be the most relevant.
( ) to understand songs in French
( ) to integrate into the community where you live / study / work
( ) to feel yourself as being part, a member of the community
( ) to make friends who are French speakers
( ) to speak without accent
( ) to enter school / university
( ) to have / look for a better job
( ) other(s): _____

APPENDIX C

The table presents the thirty-six texts used in the experiment, followed by the corresponding probes. The texts are divided according to the level of text comprehension evaluated (SIT, MAC and MIC, respectively). The translation into English is given after each text and probe, in italics. Following the texts used as stimuli, the three texts and corresponding probes constructed for the practice session are presented. The response (V/T) for *vrai/true* and (F) for *faux/false* follows each probe.

Stimuli: texts and sentence probes constructed for testing SIT, MAC and MIC level of comprehension.

Stimuli: thirty-six texts and corresponding probes
Texts for testing comprehension at the situational level

PROBE : Christophe est pressé de se rendre à son travail. (V)
Christophe is in a hurry to get at his work. (T)

TEXT 27: Claire est heureuse parce que son ami Marc l'a appelée. Ils ne se sont pas vus depuis plusieurs semaines. Ils se sont donnés rendez-vous. Elle se dépêche pour se rendre à l'endroit convenu. Arrivée la première, elle entre, s'assoit et lit le menu.
Claire is happy because his friend Marc has phoned her. They last saw each other many weeks ago. They schedule a meeting. She hurries to reach the place they have decided on. First to arrive, she enters, takes a seat and reads the menu.
PROBE : Claire est nerveuse parce qu'elle doit rencontrer Marc. (F)
Claire is nervous because she is going to meet Marc. (F)

TEXT 28: Depuis qu'elle est petite, Nathalie croit en Dieu et est pratiquante. Elle va à l'église chaque dimanche avec sa famille. Le curé de la paroisse connaît bien Nathalie. Elle participe régulièrement à la préparation de la messe dominicale.
Since she was little, Nathalie believes in God and practices her religion. She goes to church every Sunday with her family. The priest of the parish knows Nathalie very well. She regularly participates in the preparation of the Sunday service.
PROBE : Nathalie prend part à l'organisation de cérémonies religieuses. (V)
Nathalie takes part in the organization of religious ceremonies. (T)

TEXT 29: Sylvie a vraiment hâte de retrouver ses amis. Ils doivent acheter les billets et l'attendre à l'entrée. Dans l'autobus, elle essaye de se calmer. Ce sera la première fois qu'elle fera l'expérience d'une montagne russe.
Sylvie is anxious to meet her friends. They are supposed to buy the tickets and wait for her at the entrance. In the bus, she tries to get calmer. This will be her first time to try a rollercoaster.
PROBE : Les amis de Sylvie vont l'attendre près de la montagne russe. (F)
Sylvie's friends will wait for her next to the rollercoaster. (F)

TEXT 30: René regardait à travers de grandes fenêtres les gens qui saluaient leurs proches de la main. La dernière rencontre qu'il a eu avec sa mère datait d'il y a deux ans. Lorsqu'il a vu l'avion atterrir, il a couru vers les escaliers.
René watched through the big windows the people who complimented their loved ones with their hands. The last meeting that he had had with his mother had been two years before. As soon as he saw the plane landing, he ran towards the ladders.
PROBE : René avait écrit à sa mère il y a deux ans. (F)
René last wrote to his mother two years ago. (F)

TEXT 31: Marcelle a rendez-vous avec le médecin. Elle attend plus de deux heures. Elle pense rentrer chez elle, mais elle a besoin de soigner sa grippe. Elle se dit que c'est la dernière fois qu'elle vient chez ce médecin.
Marcelle has an appointment with the doctor. She waits for more than two hours. She thinks on going back home, but she needs to have her flu cured. She thinks to herself that that was the last time she was seeing that doctor.
PROBE : Marcelle pense retourner chez elle sans avoir vu le médecin. (V)

Stimuli for the practice session: texts and sentence probes constructed for testing SIT, MAC and MIC levels of comprehension.

Stimuli: three texts and corresponding probes – practice section

TEXT 1 : SIT : Paul invite son ami Maxime à manger. Maxime n'aime pas du tout l'alcool en pâtisserie. En dessert, Paul a préparé un baba au rhum. Maxime préfère finalement manger une pomme.

Paul invites his friend Maxime to eat. Maxime does not like alcohol in pasta at all. For dessert, Paul has prepared a cake with rum. Maxime finally prefers to eat an apple.

PROBE : Maxime mange une pomme parce qu'il préfère des fruits en dessert. (F)

Maxime eats an apple because he prefers fruits for dessert. (F)

TEXT 2 : MAC : Cécile aime se promener dans la nature au printemps. Les fleurs s'ouvrent et dégagent un parfum délicat. Il y a beaucoup de pollen dans l'air. Cécile a les yeux rouges et tousse.

Cécile loves to go for walks to appreciate nature during spring time. The flowers bloom and release a delicate perfume. There is plenty of pollen in the air. Cécile has her eyes red and coughs.

PROBE : Cécile fait une réaction allergique au pollen. (V)

Cécile has developed an allergic reaction against the pollen. (T)

TEXT 3: MIC : Etienne se balade à pied. Etienne est aveugle et se guide avec une canne. Il s'assoit sur un banc fraîchement peint et tache son pantalon. Une affiche indiquait la peinture fraîche.

Etienne goes for a walk. Etienne is blind and guides herself with a walking stick. She seats on a freshly-painted bench and stains her pants. A sign was indicating the fresh painting.

PROBE : Un panneau donne un avertissement aux piétons. (T)

A sign gives a warning to the pedestrians. (V)

Instructions displayed on the computer screen to start the practice session and before data acquisition. (In the practice session, the instructions were complemented by the researcher, as explained in the section "Practice session".) These instructions were presented in French and in English, according to the native language of the participant.

Instructions in English

You are invited to participate in an experiment on text comprehension.
You are going to see three types of stimuli:
* a small text
* a sentence
* a small cross
Please read the text. Then a sentence probe follows. You have to read it as fast as possible and judge if the sentence is true/possible (green button) or false/not probable (red button) in relation to the text.
The cross represents a pause. Please look at it.
Please try not to move during the experiment.
Thanks for your participation!

Instructions in French

Vous êtes invités à participer à une expérience sur la compréhension de texte.
La tâche consiste en trois différentes étapes
* Premièrement, un petit texte apparaîtra à l'écran
* Après le texte, une seule phrase apparaîtra à l'écran
* Enfin, vous verrez une croix au centre de l'écran
La tâche consiste donc à lire le texte. Après la lecture du texte, une phrase apparaîtra à l'écran. Vous devez lire la phrase le plus rapidement possible et juger si elle est vraie/possible (bouton vert) ou fausse/ non possible (bouton rouge) en fonction du texte que vous venez de lire. Finalement, la croix représente une pause entre deux stimuli et vous devez la regarder.
SVP d'éviter de bouger pendant la tâche.
Merci de votre participation