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"The neural correlates of verbs and nouns: a MEG study on Italian homophones"

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“The neural correlates of verbs and nouns: a MEG study on Italian homophones”

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To Georgia

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Abstract

The neural correlates of nouns and verbs are the central issue of a long-standing debate in neuropsychology. The double dissociability of the two grammatical categories and of the respective morphosyntactic processes has been firmly established in neuropsychological studies (eg, Shapiro & Caramazza, 2003a; Drucks, 2002) leading to the hypothesis that verbs and nouns, as well as the involved morphosyntactic operations, have distinct neural representations. However, neuroimaging findings provide only inconsistent support to these hypotheses, which could be due in part to the limitations intrinsic to the various neuroimaging tools. In the present study, the neural representation of Noun/Verb distinctions is studied by means of a novel technique - magnetoencephalography (MEG), which is characterized by excellent temporal resolution and good spatial resolution. The goal of the study is to establish whether distinct neural substrates are involved in processing nouns and verbs in the context of phrases.

In an adaptation paradigm we presented Italian homophonous noun and verbs. Homophones were selected because they share the same word form but belong to different grammatical categories. The homophones nouns and verbs were presented in minimal syntactical context: article and noun, pronoun and verb (eg, il ballo/i balli, the dance/the dances; io ballo/tu ballii, I dance/you dance). Twelve healthy participants performed a silent reading task, and their spatiotemporal information was measured during the processing of homophones.

The analysis conducted on the evoked responses of noun and verb phrases identified the response components of lexical processing and the differences between the two grammatical categories. A localization technique was employed to isolate the corresponding differences in the cerebral topographies.

The resultant differences revealed partially matching neural substrates during the early processing of both grammatical categories that diverged in the later stages of processing. Both nouns and verbs activated the occipital, left temporal and parietal regions but only verbs engaged the left inferior frontal gyrus during the late time window. Our results are comparable to findings of the clinical reports: verbs were mainly processed at the left frontal cortex while nouns activated the left temporal lobe.

These findings support the hypothesis that at least partially distinct neural structures are involved in the processing/representation of verbs and nouns and of their respective morphosyntactic operations. MEG appears to be a promising tool for the analysis of the spatiotemporal dynamics of the networks implicated in language processing.

Key words: MEG, verbs, nouns, frontal lobe, temporal lobe, aphasia

Chapter 1 - Background

1.1 Introduction

One of the most consistent findings in aphasiology is the double dissociation between nouns and verbs. Miceli, Silveri & Villa, (1984) reported anomic patients with posterior cortical lesions that had trouble naming nouns and agrammatics with anterior lesions areas that had difficulties with verb processing. The distinction of the two grammatical classes has since been extensively documented by clinical reports and these findings have since been substantiated by a number of subsequent studies (Shapiro & Caramazza, 2003b; Tsapkini, Jarema & Kehayia, 2002; Caramazza & Hillis, 1991; Damasio & Tranel, 1993). Brain-damaged patients with disproportionate patterns have been frequently identified: some patients showed impairments in verbal processing while nouns remained intact (Miceli, et al., 1984; Rapp & Caramazza, 1997) and other patients exhibited the reverse deficit (Damasio & Tranel, 1993).

The neuropathological data have linked the double dissociation with distinct cerebral areas; verb deficits are usually identified in patients with lesions to the left frontal cortex while damage to the left temporal lobe impairs nominal processing. As the anatomical distinction of this functional difference would have important implications for our understanding of the lexical organization, extensive research has focused on revealing the neural circuits subserving noun and verb processing. While an ample amount of electrophysiological and neuroimaging studies have offered a valuable insight on the association between the functional difference and the anatomical segregation of the two word classes, the findings remain variable and challenging to interpret.

The lack of consistency of the neuroimaging data has been attributed to a number of reasons: a. the type of the primary task (visual or auditory), b. the type of the 'experimental' condition within the primary task (e.g. picture naming, word elicitation etc.), c. the tool and methodological aspects including the statistical approach, and the baseline (Crepaldi, Berlingeri, & Paulesu, 2011).

The variability of the neuroimaging findings have further expanded the debate and gave rise to an argument regarding the potential psycholinguistic explanations of the word class distinction. Grammatical accounts attribute the double dissociation to moprho-syntactic aspects specific to the word classes whereas the semantic-conceptual accounts differentiate the two word classes based on their semantic features. Verbs are action-oriented while nouns denote objects. Lastly, the lexical accounts claim distinct neural representations of the two word classes independent of their semantic features.

Overall, the double dissociation has not been consistently replicated by neuroimaging studies. There is a diversity of findings depending on the tool and the task employed in each study. The debated on the plausible interpretations of the noun-verb distinction reflects the core of the main concern in language research: the organization of the lexical system and its components.

In view of that, we employed Magnetoencephalography (MEG) -a tool that can assess cognitive processing with the millisecond precision and simultaneously locate the active brain regions - in order to investigate the following question:

Is verbal and nominal processing regulated by a common neuromechanism or modulated by at least partially distinct neuronal networks?

The investigation of this issue will offer a better understanding of the neurophysiological underpinnings of grammatical impairments. Therapeutically, this implies the development of improved treatment strategies. The investigation of this issue will also offer a window on lexical organization and an understanding of how it is realized in the brain.

1.2 Literature Review

This section starts with an introduction of the noun-verb dissociation issues as portrayed by the clinical data, and then reviews the evidence yielded by electrophysiological and neuromaging studies and the possible explanations for the divergent findings as well as the neuropsychological interpretations. Finally, it provides a brief review of the MEG method and its applications in comparison with the other tools.

1.2.1 Clinical data

The dissociation between nouns and verbs has been extensively documented in aphasiological data (Shapiro & Caramazza, 2003b; Tsapkini et al., 2002; Caramazza & Hillis, 1991; Damasio & Tranel, 1993) findings report on aphasic patients with disproportionate problems of either of these two word classes. Furthermore, the dissociation has been identified by a variety of tasks in different modalities such as picture naming tasks, writing tasks, spontaneous speech etc. What remains robust is the association between verbal processing and left frontal regions, and nominal processing and left temporal areas (Damasio & Tranel, 1993). There are, however, cases that implicated additional areas in the processing of one category (Silveri & Di Betta, 1997) and patients with frontal lobe lesions that showed impaired noun processing (Shapiro, Pascual-Leone & Mottaghy et al., 2001). In general, the assumption that grammatical categories are processed in distinct cortical areas is a consequence of the numerous reports on patients with impairments on word classes in combination with specific brain damage (Damasio & Tranel, 1993).

The neuropsychological evidence posed a number of questions and triggered a long-standing debate. Furthermore, it endorsed a systematic investigation of the neural underpinnings of noun and verb by means of a variety of neuroimaging tools and tasks.

1.2.2 Neuroimaging data

fMRI and PET studies have identified the left prefrontal and medial frontal cortex as verb-selective areas (Raichle, Fiez, & Videen, 1994; Wise, Chollet, & Hadar, 1991; Petersen, Fox & Posner, 1988; 1989). However, other PET studies have failed to identify differential neuronal substrates for nouns and verbs; Warburton, Wise & Price, (1996) used a word generation task to identify a large left lateralized network engaged by both nouns and verbs including temporal, parietal and prefrontal regions. However, no distinctive regions were identified specific to either class. Similarly, Perani, Cappa & Schnur, (1999) with a lexical decision task and Tyler, Russell & Fadili, (2001) with a semantic categorization task found no neurological correlates for the grammatical classes under investigation. On the other hand, Shapiro, Mottaghy, & Schiller (2005) found greater activity for the verbs over the left frontal cortical network while nouns showed greater activation in bilateral temporal regions, using a cued elicitation task in a PET study.

Similar variability in the findings is depicted by the fMRI literature. For example, Longe, Randall & Stamatakis, (2007) used valence judgment paradigm to contrast morphologically simple and complex words. While the uninflected verbs and nouns did not show differential activation, the inflected verbs engaged the posterior portion of the left mid temporal gyrus while no area was predominantly activated for the nouns. Thompson, Bonakdarpour & Blumenfeld, (2004) obtained comparable results using a lexical decision task. Verbs elicited pronounced activation in Broca's and Wernicke's area as well as in the superior and posterior regions of the parietal lobe while nouns exhibited more widespread and little perisylvian activation. To demonstrate the extend of the variability, Tyler, Randall & Stamatakis, (2008) found a correlation between verb processing and the left posterior middle temporal gyrus but no region active for noun processing. The task employed was a pleasantness judgement task with or without a syntactic context. In a picture naming task, Berlingeri, Crepaldi & Roberti, (2008) reported bilateral activation for the verbs widespread to a patchwork of regions such as the frontal, temporal, and parietal while no brain areas were activated more by nouns than by verbs.

On the contrary, a different pattern emerged in the study by Corina, Gibson & Martin, (2005) where cortical stimulation of the left anterior superior and of the left middle temporal gyrus caused failure to name pictures of nouns/objects while the verb related areas varied across patients over the left middle superior temporal gyrus, the left supramarginal gyrus and the left posterior middle temporal gyrus.

Studies using repetitive transcranial magnetic stimulation (rTMS) also showed variable patterns of activation for nouns and verbs and further demonstrated the effect of the tasks.

Shapiro et al., (2001) found increased reaction times for producing inflected verbs following rTMS at the left prefrontal cortex but not for inflected nouns. The authors concluded that the findings suggest that nouns and verbs have distinct neuroanatomical correlates with respect to grammatical category and the left prefrontal cortex is involved in the processing of grammatical information of verbs. In contrast, stimulation to the same region did not yield the same results in a picture naming task by Cappa, Sandrini & Rossini, (2002). The two studies mainly differed in the task they employed leading to the conclusion that the left prefrontal cortex is involved in morphological processing of verbs but not in their retrieval (Crepaldi et al., 2011). However, a study with a focus on the prefrontal cortex and its implications in noun and verb processing identified the midfrontal cortex more crucial for the morphological processing of verbs than nouns (Capelletti et al., 2008).

Electrophysiological findings have consistently displayed an increased left-lateralized anterior positivity associated with the processing of verbs compared to the nouns. This effect is specific to unambiguous verbs and was not sustained for ambiguous verbs or when the syntactic context set up the expectation for a noun (Dehaene, 1995; Federmeier, Segal & Lombrozo, 2000). A functional difference in processing was also assumed by the findings of Gomes, Ritter & Tartter, (1997) that found a divergence in the temporal patterns of nouns and verbs, but no corresponding topographical differences. However, Koenig & Lehmann, (1996) observed spatiotemporal differences between the two word classes. Distinct neuronal activity patterns for nouns and verbs were supported by Pulvermüller, Preißl & Lutzenberger (1996; 1999). Verbs elicited greater activations over the motor sensors, while nouns exhibited stronger activity over the visual cortex. More recently, Khader & Rösler, (2004) examined the spectral correlates of noun and verb and identified spectral changes that suggest differences specific to the grammatical categories. The differences were located over the left frontal regions, the inferior frontal gyrus and Brodmann Area 45.

Magnetoencephalography (MEG) has recently been employed by a number of studies to assess the spatiotemporal correlates of the two grammatical categories. MEG exhibits a better temporal resolution than EEG and combines it with accurate spatial information which allows for a closer and more precise exploration of the processing of nouns and verbs. Similarly to the fMRI and PET data, the findings displayed a considerable variability. Sörös, Cornelissen & Laine, (2003) used a picture naming task to assess the neural pathways of verbal and nominal processing. Healthy participants showed identical patterns of activations for verb and noun retrieval whereas an aphasic patient with noun naming deficits showed an ample deviation. Differences between the two grammatical classes were located during an early time window (100-200 ms) by Liljeström, Hultén & Parkkonen, (2009). The authors used and action-object naming paradigm and found enhanced early activation of the right frontal and bilateral parietal cortex for noun retrieval. While verbs engaged the anterior superior temporal lobe, the activation was not robust and varied across subjects. No other time intervals exhibited noun-verb differences. More robust results were reported by Xiang & Xiao (2009), in a silent reading task. Nouns and verbs engaged identical regions during early processing and low frequency, but the spatiotemporal sequence diverged during late latency and high frequency. In a word category judgment task, Fiedbach et al., (2002) examined the effects of syntactic context on the processing of the grammatical classes. The authors identified no word category differentiation when German nouns and verbs were presented in isolation. However, when presented in a minimum syntactic context, nouns exhibited stronger magnetic fields over the left posterior temporal regions.

The robust double dissociation between nouns and verbs and the lack of consistency in this systematic investigation created an ongoing discussion regarding the processing components of the lexical organization searching for answers in a grammatical, semantic-conceptual or lexical explanation.

1.3 Theoretical accounts on the differences between nouns and verbs

Along these lines, a number of theoretical frameworks have been developed to account for the double dissociation (Bates, Chen & Tzeng, 1991).

The grammatical accounts claim that the differences concern principally the morpho-syntactic aspects of nouns and verbs. Verbs own complex morpho-syntactic properties – compared to nouns- that accentuate their role in the syntactic construction. The importance of inflectional morphology has been revealed by patients that exhibit deficits in inflecting one grammatical class while the other remains intact even if it is a homophone (e.g. judge/ judges) or a nonsense word (e.g. wug/wugs) (Shapiro & Caramazza, 2003b). In this view, verb deficits reflect impairments in syntactic function, as exhibited by selective impairments of agrammatic patients (e.g. Silveri, Perri & Cappa, 2003, Caramazza & Hillis, 1991; Miceli et al., 1984). However, Shapiro et al., (2001;

2005) commented that it is uncertain whether information regarding the semantic or the grammatical functions is retained by patients exhibiting noun and verb deficits.

The semantic-conceptual accounts distinguish between the class categories based on different domains of meaning. The semantic representation of verbs is action-oriented, stored in anterior motor regions. Nouns, on the other hand, are semantically represented by objects with more perceptual features than verbs and are stored at sensory cortex. This differential distribution of semantic features may be implicated in the word class effects (Damasio & Tranel, 1993; Pulvermuller et al., 1999). Marshall (2003) suggested that since verbs are less imageable than nouns, they are more prone to semantic damage. The action-object distinction has been utilized as the basis of the comparison between nouns and verbs in some neuroimaging studies. Some of these reports identified differences in processing (Gomes et al., 1997; Grossman, Koenig & DeVita, 2002) whereas others did not (Warburton et al., 1996). Alongside studies that focused on meaning representation and matched the semantic properties of their verb and noun stimuli such as Tyler et al., (2001) and Perani et al., (1999) did not find distinct patterns of activation for nouns and verbs. On the other hand, grammatically ambiguous words with motor representations did not induce a left frontal positivity as postulated by other findings (Federmeier et al., 2000). Differences between the two word classes cannot be considered utterly the effect of their grammatical status since their semantic properties also differ in a vast degree. Further, the semantic interpretation has been challenged since it cannot account for all word class effects (Shapiro & Caramazza, 2003a). One of the arguments holds that nouns can often refer to actions and assume thematic roles. Additional evidence is the modality specific impairments as shown by a number of cases (e.g. Miceli, Silveri & Nocentini, 1988; Kim & Thompson, 2000). An illustrative case is the patient presented by Caramazza & Hillis (1991) that had deficits in verb production but comprehension was spared. Such evidence has served as the foundation for the lexical interpretations. The lexical accounts maintain that verbs and nouns are stored in separate regions within the lexicon, independent of semantics. The word class deficits are considered isolated to the lexical level and dissociations are related with the processing of one form class (Miceli et al., 1984; 1988; Caramazza & Hillis, 1991).

Each of the three types of accounts briefly described above can explain some cases of grammatical class impairments. The reasons of the word class effects are diverse, and vary with every individual. It is possible some impairment could hold at a combination of levels without challenging alternative accounts. The different explanations do not need to be conflicting but could be considered in conjunction to explain certain patterns of aphasic behavior that despite of the common symptoms, exhibit different causes.

1.4 Speculations on the diversity of neuroimaging data

As shown by the brief review of the literature, the diversity of the findings is striking. In spite of the abundance of data, the investigation of the noun-verb dissociation in healthy participants remains tentative.

A number of reasons have been considered to explain the inconsistent findings of the neuroimaging research as reviewed in detail by Crepaldi et al., (2011). The authors considered the wide range of tasks as one of the key factors. Lexical decision, picture naming, semantic decision etc. have been employed to measure the same processes without taking into consideration the cognitive levels of processing involved in each of these paradigms. These processing mechanisms do not discriminate between noun and verb processing and further interact with a number of other variables such as semantics, syntax and phonology. Consequently, Crepaldi et al., (2011) suggested that a baseline reflecting the cognitive processes specific to each task is essential when comparing with the experimental condition. An additional point regarding the methodological aspects of each study is the effect of the various statistical analyses employed. Moreover, factors such as frequency, imageability and stimulus complexity are potential confound variables. These lexical-semantic dimensions differ across grammatical classes and often create difficulties in designing a reliable experimental paradigm and consequently, in disentangling their effect from the one under investigation.

Regarding the interplay between lesion and neuroimaging data, it has been stated that the latter can identify the areas that are activated during the task but cannot inform us which regions are essentially involved in those tasks (Price, 2000; Hillis & Caramazza, 1995). Lesion data, on the other hand, is more indicative of the areas required for task performance. The cortical stimulation study by Corina et al., (2005) indirectly addressed the divergence between lesion and neuroimaging data of noun and verb naming. As shown, the areas activated by the picture naming task considerably varied not only across the patients but also in the individual patients. The comparison across tools was addressed by Liljeström et al., (2009) who reported good convergence of the MEG and fMRI findings. The authors used the exact same experimental design with both tools and identified comparable activation patterns and localization results. However, they still documented some inconsistencies, especially across the individual participants.

It is essential to consider the features of the neuroimaging tool employed in each investigation and assess the type of information it provides. An overview of the advantages and limitations of the tool can provide us with a better perspective on the interpretation of the results. In the current investigation, MEG was considered suitable for the purposes of our study.

1.5 Magnetoencephalography (MEG) neuroimaging

1.5.1 MEG

MEG is a noninvasive imaging technique and has become an important instrument for the study of brain. Clinicians and researchers have efficiently employed MEG for identifying regions affected by pathology and assessing behavioral and cognitive processing (Volkmann, Joliot & Mogilner , 1996; Kotini, Anninos & Anastasiadis, 2005). MEG shows good spatial resolution and retains extremely accurate temporal resolution (ms). MEG signal records the fast changing neuromagnetic fields outside the head using arrays of superconducting quantum interference devices (SQUIDs). It is a direct measure of neuronal activity that exhibits substantial similarities and differences with other neurophysiological and hemodynamic tools.

1.5.2 MEG and EEG

Both the electric and magnetic signal derive from the same neurophysiological mechanism but in contrast to EEG which measures electrical potentials at the scalp, MEG measures magnetic fields outside the head. Neuromagnetic fields are less affected by the intermediate structures of the head (skull and scalp) than EEGs and consequently exhibit higher localization accuracy. MEG allows for the separation of different components (i. e. steps of information processing) and the topographical mappings are less smeared than in EEG. Finally, MEG is reference-free while EEG relies on the location of a reference electrode. Therefore, the interpretation of MEG data is considered to be easier and source localization more accurate than with EEG (Kristeva-Feige, Rossi & Feige, 1997). There are, however, findings that doubt the superiority of MEG's localization accuracy over EEG (Cohen & Cuffin, 1991). Nevertheless, for the purposes of the present investigation, MEG exhibits all the required properties.

1.5.3 MEG and other tools

One of the advantages of MEG compared to other functional neuroimaging modalities is that it is non-invasive. MEG does not require the placement of multiple electrodes on the scalp as in EEG or the injection of a radiotracer into the blood circulation as in PET. The MEG signal measures the primary neuronal discharges and therefore tracks activation with extremely high precision. Functional MRI (fMRI) and PET measure the changes in the blood oxygenation levels and assess the metabolic activity across the brain. Both PET and fMRI measure changes with a lower temporal resolution than MEG, and consequently cannot detect neuronal currents (Horwitz, Fristonb & Taylorc, 2000).

MEG is considered to be one of the most efficient tools for studying language and specifically lexical processing. The good spatial resolution and the highly precise real time tracking of neural activity depict the cortical processes occurring sequentially and simultaneously, identify the neural correlates that may overlap between time points in different brain areas (Salmelin, 2007). MEG provides the essential spatiotemporal information for determining the neural correlates of lexical activation. Salmelin, (2007) argued that the analysis of fMRI/PET data has shown that these tools were not able to detect the onset of letter-string specific analysis -during a reading task- which caused subtle differences at the left occipitotemporal activation, identified only by MEG. However, the authors discussed alternative findings by Cornelissen, Tarkiainen & Helenius, (2003) where MEG could not detect activation which was not strictly time-locked to stimulus presentation whereas fMRI/PET was not bound by this condition. Additionally in a meta-analysis of 35 neuroimaging studies (fMRI/PET and MEG), Jobarda, Crivello & Tzourio-Mazoyera, (2003) observed that the consensus among findings in semantic and phonological research was poor.

It is clear that each tool has a set of assets and drawbacks that need to be thoroughly considered in order to choose the suitable one. For the purposes of the present study we chose MEG over other functional neuroimaging modalities because it provides an incomparable sensitivity to primary neuronal discharges, real time tracking down to milliseconds and good spatial resolution over the overlap of time course in distinct brain areas; these properties are essential for the present investigation that examines a complicated cognitive process such as the processing of grammatical class.

1.6 The Present Study

The present study examines the processing of homophonous noun and verb phrases in Italian in a silent reading task, with means of Magnetoencephalography (MEG). The primary aim of this investigation is to address the debate regarding the noun-verb dissociation and examine the neural regions subserving the two grammatical categories. To achieve this goal, we designed a study that includes the two following important aspects: 1. carefully selected homophonous nouns and verbs that serve to isolate the grammatical class effect; 2. MEG, a tool with a precision of milliseconds to assess the cortical activation. Following the event-related field analysis of the MEG data, we examine the temporal differences of the two grammatical classes in their global and local field power activity patterns. The identifiable temporal differences will be spatially localized by the method of Minimum Norm Estimates (MNE) source analysis.

The goals of this investigation are to: 1. exemplify the electromagnetic responses to silent reading task in healthy participants; 2. identify the patterns of activation of the grammatical classes and cortically localize their differences; 3. address the existing accounts on the noun-verb dissociation.

The first goal assesses the response components of lexical processing, the second goal assesses the spatial divergence of verbs and nouns and the final one assesses common interpretations of the noun-verb dissociation in relation to our findings. Undertaking these goals will offer additional evidence to address the long-standing debate on the class categories and to indirectly tackle the issue of lexical organization and its dynamics. The optimum goal would be to improve our understanding of the language system and hence, of the language difficulties and their treatment.

Chapter 2 – Materials & Methods

2.1 Participants

Thirteen healthy native Italian speakers participated in this study. All participants were right-handed with normal or corrected vision and none of them reported a history of serious head injury or neurological disease. Prior to testing a written informed consent was obtained from each participant. Compensation was given for their participation following the completion of the experiment. The research protocol was approved by the local ethical committee. Due to noise sources identified after the recording session, the data of one participant was excluded from the analysis. The MEG recordings of the remaining twelve participants (age: 23-34, mean age: 27; 5 females and 7 males) were analyzed for the present study.

2.2 Stimuli and Task

2.2.1 Selection of Stimuli

The homophone stimuli were extracted from the ‘itWaC’ corpus (Baroni, Bernardini & Ferraresi, 2009). The obtained items had identical word forms and functioned as both nouns and verbs in Italian. The selected type of homophones had also identical word forms for the second person singular (for the verb) and the plural (for the noun) which allowed the possibility to examine the morphological operations.

The preliminary batch of words contained hundreds of Italian homophones that were then filtered for obsolete forms, word length and frequency. The obsolete words were excluded and the word length was defined to a maximum of four syllables. Likewise, a frequency threshold was set at 1000-354268 in order to eliminate items with extremely low or high frequency. Finally, 12 Italian native speakers reviewed the resulting material to ensure the exclusion of obsolete items, or forms that are not used in Standard Modern Italian. Considering the variability of the reviewers regarding their native dialects, only the items that were selected unanimously were included in the final material, which were then approximately matched on lemma frequency. Furthermore, the word form frequency was taken into account because of many instances that had extremely high or low word form frequency as one class category but not as the other one.

Particularly, the main objective of this task was to primarily match the lemma frequencies between the noun and verb homophones and then consider the word form frequency in order to avoid possible frequency effects with confounding character.

Findings showed that lexical frequency had additive effects on the brain activation in occipitotemporal regions in an fMRI study (Kronbichler, Hutzler & Wimmer, 2004) and on the amplitude of the ERP (Hauk & Pulvermuller, 2004). Therefore, it was essential to control for variables that may create a frequency effect that may contaminate the data. However, considering the nature of the Italian homophones, the matching process between nouns and verbs could materialize only in approximation. Therefore, as described above, more than one selection strategy was implemented; the matching of the homophones was based on both the lemma frequency and the word form frequency.

In addition, it should be mentioned that Italian masculine nouns have two types of articles: IL (plural: I) and LO (plural: GLI). The former is a pure article while the latter functions also as a pronoun as illustrated in the Table 1:

Italian Definite Masculine Articles	
Singular	**Plural**
IL e.g. il bacio (the kiss)	**I** e.g. i baci (the kisses)
and	
LO used before sc/sp/st/gn/z **L'** used before vowels e.g. l'uomo (the man)	**GLI** e.g. gli uomini (men) gli stimoli (urges)

LO as a Clitic	
(1) Michele **lo** legge. Michele CL.ACC reads 'Michele reads it.'	(2) Lo sapevo it knew-1SG 'I knew it!'

Table 1 Italian Definite Masculine Articles

It is established that articles, compared to pronouns, are highly frequent in Italian, especially article IL compared to LO (Bertinetto, Burani & Laudanna, 2005). The selection process resulted in a limited pool of items that made it impractical to avoid noun homophones utilizing the article LO. For this reason, a frequency analysis was performed to compare the activation of the two articles and examine whether there were significant confounding differences that affect the data.

The final list was lastly reviewed by 12 Italian native speakers and resulted into 66 homophones that are presented in Appendix A.

2.2.2 Experimental Paradigm

The 66 homophones were visually presented in pairs. We used an event-related adaptation paradigm in which the paired homophones were presented consecutively in each trial as shown in figure 1. There was no interstimulus interval between the two consecutively presented stimuli in order to instigate the adaptation effect.

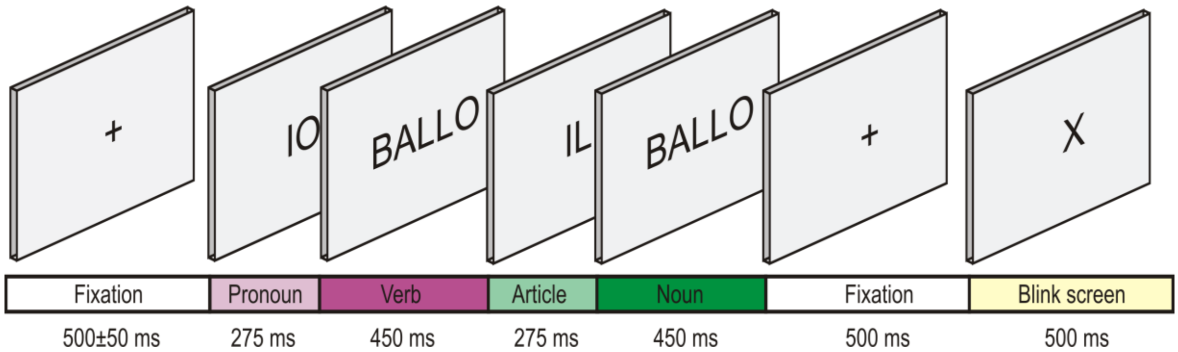

Figure 1 . Schematic illustration of a single trial of the silent reading task

The homophone pairs were divided into the following five conditions:

(1) Identity pairs, in which the two homophones were identical (e.g. io ballo-io ballo or il ballo-il ballo) and functioned as the control condition;

(2) Grammatical pairs, in which the two homophones differed only in grammatical class (e.g. io ballo-il ballo, il ballo-io ballo) and functioned as the main experimental condition;

(3) Morphosyntactic pairs, in which the two homophones differed either in conjugation (verbs) or in number (nouns) (e.g. io ballo-tu balli, il ballo-i balli);

(4) Orthographic pairs where both parts of pair belonged to the same grammatical class while the first homophone was followed by an orthographically similar word (e.g. io ballo-io bollo, il ballo-io bollo);

(5) Pseudoword pairs, in which the first homophone was followed by a pseudoword. Pseusowords were phonologically acceptable in Italian and formed by changing a single phoneme in the real word.

The word-pseudoword pairs intended to control alertness, attention and ensure the reading process. Their presence was exclusively functional and not investigative in nature. For this reason, reaction times were not thoroughly examined during data analysis, as they were not a fundamental part of the objective of the study.

The participants were instructed to decide whether the second word in each pair was a real word or pseudoword and respond by lifting their finger at the response pad. They were asked to respond following the offset of the pseudoword during the appearance of the fixation point. These conditions are schematically illustrated in Table 2.

IDENTITY

NOUN	VERB
IL BALLO – IL BALLO	IO BALLO – IO BALLO
I BALLI – I BALLI	TU BALLI – TU BALLI

ORTHOGRAPHIC SIMILARITY

NOUN	VERB
IL BALLO-IL BARO	IO BALLO-IO BOLLO
I BALLI-I BAFFI	TU BALLI-TU FALLI

MORPHOSYNTAX

NOUN	VERB
IL BALLO-I BALLI	TIO BALLO-TU BALLO
I BALLI-IL BALLO	TU BALLI-IO BALLO

GRAMMATICAL CLASS

Singular NOUN/1st person VERB	Plural NOUN/2nd person VERB
IL BALLO – IO BALLO	I BALLI – TU BALLI
1st person VERB/ Singular NOUN	2nd person VERB/ Plural NOUN
IO BALLO– IL BALLO	TU BALLI – I BALLI

Table 2 The four conditions

The stimuli was divided in four conditions.: (1) Identity; (2) Grammatical; (3) Morphosyntactic; (4) Orthographic

The stimulation paradigm was designed to tackle the grammatical class features by enhancing the adaptation effects. Moreover, the neural activation induced by the morphological processing of number and conjugation was a further interest that was specifically targeted by the Morphosyntactic condition. The adaptation paradigm was considered to be suitable along the lines of the hypothesis investigated in the present work. As discussed in Chapter 1, the main debate addresses the neuronal networks regulating verbal and nominal processing in the brain: a common neuromechanism versus distinct neuronal systems. An adaptation paradigm offers the possibility to detect the subtle differences between verbs and nouns when they are modulated by a common neuromechanism or to register the palpable activation when it derives from distinct neuronal areas. The subtraction method, a feature of the adaptation paradigm, is very informative since it allows for a variety of comparisons. The main advantage of this paradigm is that the subtractions between the baseline (identity) and the experimental conditions will reveal the activity patterns under investigation.

2.3 MEG Recording Session

2.3.1 MEG Recording Session: Procedure

The MEG recording session was carried out in the electromagnetically shielded room of the MEG lab at the Functional Neuroimaging Lab (LNiF). MEG signals were measured with the 306-channnel Elekta Neuromag system. Prior to MEG recording, four electromagnetic coils were attached to the scalp of each participant serving as head-position indicators (HPI coils). The coils were secured on the head with medical tape. The location of these coils and the head shape of each participant were recorded with a 3D digitizer (Polhemus Fastrak) with respect to three anatomical landmarks: the nasion and the two-periauricular points. The four coils attached to the participant's head could be localized by the MEG system and thus the headshape, recorded by the 3D-digitizer, could be co-registered with the MEG recording. The digitization procedure provides a head coordinate system for each participant that allows the visualization of his/hers MEG measurements on a spherical model created with reference to the head shape digitization. Therefore, it makes source localization feasible when structural MRI data is not available for each participant. Further, it allows the alignment of functional MEG and anatomical magnetic resonance imaging (MRI) data in case of availability of individual MRs. After digitization, the participant was situated in a magnetically shielded, quiet and dim-lighted room and comfortably seated in the MEG apparatus. The subject's head was placed in the helmet-shaped sensor area of the MEG.

Stimuli were presented on a back projection screen (112cm) located approximately 126 cm in front of the participants. The stimuli subtended an angle of maximally five degrees of the center of the visual field in order to avoid eye movements. E-Prime® 2.0 (Psychology Software Tools, Inc. Pittsburgh, PA) software was used for the presentation of stimuli. In order to correct for delays of in stimulus presentation, a photodiode - attached discreetly on the projection screen - detected the projected stimuli and promptly sent a trigger to the MEG acquisition system. For the recording of the responses during the on-line data acquisition, a single digit response pad - activated by a finger lift - was placed on the right side of the participant on a removable table.

2.3.2 MEG Recording Session: Task

The participants were briefed in detail regarding the task. Subsequently, they completed a brief training session prior to the experiment. They were instructed to read silently the stimuli presented on the screen, identify the pseudowords and communicate their decision by lifting their right index finger at the response pad.

The stimuli were presented serially with every word appearing in a single frame. The duration of the experiment was approximately 56 minutes and consisted of 1088 trials. Each session was divided into 8 blocks (136 trials each) which lasted approximately 7 minutes. The participants could rest between the blocks.

Participants were instructed to fixate on the central fixation point that appeared for a fixed interstimulus interval (500±50ms) and successively replaced by the homophone phrases. The homophone pairs were then presented one word at a time in the centre of the screen; the function words were presented for 275ms and the homophones for 450ms. The length of the presentation of the stimuli was assigned after taking into consideration evidence suggesting function and content words are processed differentially. Specifically, access times for function words are considerably faster than for content words as shown by electrophysiological evidence. These differences have been attributed to frequency effect and word predictability (Chiarello and Nuding, 1987; Sidney et al, 2000).

The last word in each trial was followed by a fixation point that appeared on the screen for 500ms. The fixation point was then replaced by a screen displaying an X for another 500ms. Participants were asked to refrain from blinking during the word presentation in order to minimize artifacts in the MEG recording. They were instructed to blink freely and communicate their response when the 'X' screen appeared in order to avoid movement/muscle artifacts during the stimuli presentation.

2.4 MEG recordings

2.4.1 Data Acquisition

MEG data was recorded with a 306-channel MEG array (Elekta Neuromag). The sensor array consists of 204 gradiometers and 102 magnetometers. Gradiometers show more focal sensitivity and less susceptibility to external noise than the magnetometers. In the present study, the analysis performed on the data was acquired by both types of channels. Raw data were filtered with a band pass filter between 0.1 and 330 Hz, and sampled with a rate of 1000 Hz.

Following the acquisition, the raw MEG data were analyzed using brain electric source analysis (BESA) software package (MEGIS Software GmbH, Gräfelfing, Germany). The recorded data was high-pass filtered at 1.6 HZ and low-pass filtered at 60 Hz. The filtered data was baseline corrected by subtracting the mean activity in the 500 ms lasting prestimulus interval for each channel. At the first part of the analysis, for the event-related field (ERF), global field power (GFP) and local field power (LFP)peak analyses, the epochs used lasted from -100 to 725ms. For the subtraction comparisons, we used the entire epoch, -100 to 1450. Epochs were visually inspected in order to remove movement-related artifacts. The epochs contaminated with eye or head movements and muscle-related artifacts were excluded from averaging. The artifact-free MEG signals were firstly averaged for each subject and then for all subjects for the conditions under investigation. For the five conditions a minimum of 5500 artifact-free responses were averaged while for the remaining subconditions a minimum of 550 epochs was used to calculate the averaged waveforms. The global field power corresponds to the spatial standard deviation of the amount of activity across the scalp at each time point and reflects the power from all recording electrodes simultaneously (Skrandles, 1990). We calculated the GFP for each participant and each condition and subsequently did the same for the LFP. The latter functions similar to the GFP but it reflected the power from the recording electrodes we selected based on the regions of interest. The computation of global field power yielded a number of components, which were further analyzed separately suing repeated measures ANOVAs while Significance was set at $p<.05$. The topographical information of the resultant statistical significant differences were investigated but the Minimum Norm Estimates (MNE).

2.4.3 Minimum Norm Estimates (MNE)-source localization

The cortical sources of the measured neuromagnetic fields were determined by using minimum-norm estimates (MNE). This method does not require any explicit a priori assumptions about the nature or the number of the source currents (Hämäläinen & Ilmoniemi, 1994). Findings have shown that MNEs depict the structure of the primary current distribution with great accuracy, which correlates positively with the numbers of measurements (Hämäläinen & Ilmoniemi, 1994; Uutela, Hämäläinen & Somersalo, 1999). For the above-mentioned reasons we preferred this localization technique. The MNE were analyzed for the data of each participant individually for specific time points and subsequently source activity in the areas of interest was quantified. For statistical analysis, we employed analysis of variance (ANOVA-repeated measures), performed with MATLAB® software (2009b, The MathWorks Inc., Natick, Massachusetts). Significance was determined at $p<.05$.

Chapter 3 - Results

The analysis of the data occurred in two stages: Firstly, we focused on the first homophone phrase of the trial (0-725 ms) and examined the temporal and spatial course of the activation patterns induced by noun and verb processing. The analysis identified the lexical components of both class categories and defined their time intervals. The statistical analysis of the root mean square values of the global field activity yielded statistically significant differences in the spatiotemporal processing of the two word categories.

Based on the adaptation paradigm, in the second step, we employed the subtraction analysis. We evaluated the whole trial (-100-1450 ms) as a single entity aiming to compare the various experimental conditions with the baseline by subtracting their global field activity. Specifically, the baseline condition was subtracted from the condition where we manipulated the variable of interest. In this fashion, we aimed to assess the differences between nouns and verbs and of their morphological operations. However, the paradigm was proved barren for our experimental design and in view of that, we evaluated the commonalities of the activation patterns between the two class categories and assessed the differences. We compared the three conditions consisting of either a homophone or an orthographically similar word against the baseline condition -that did not contain any morphological change.

Based on the results of the abovementioned analyses we proceeded with an essential phase of the investigation: the assessment of the lexical frequencies of the articles and pronouns, and their comparison. Furthermore, the nature of dual identity of the article-pronoun ‘LO’ (Plural: ‘GLI’) required additional assessment in order to exclude the effect of confound variables in our findings.

3.1 Behavioral results

On average, participants identified the pseudoword correctly 92% of the time at the second part of the pair (range 85-95%). Generally, the behavioral results showed that volunteers were actively participating in the experiment and attending to the stimuli.

3.2. Time course activity during silent reading of nouns and verbs

3.2.1. Event-related field (ERF) peak analysis

The brain responses induced by the neuromagnetic fields of noun and verb processing were identified in latency from 0 to 725ms. The recorded event-related magnetic fields of the class categories were composed of the following components: Three components were identified for the function word and four for the content word. They were respectively named FM1, FM2, FM3 and CM1, CM2, CM3, CM4 and they are illustrated in Figure 2.

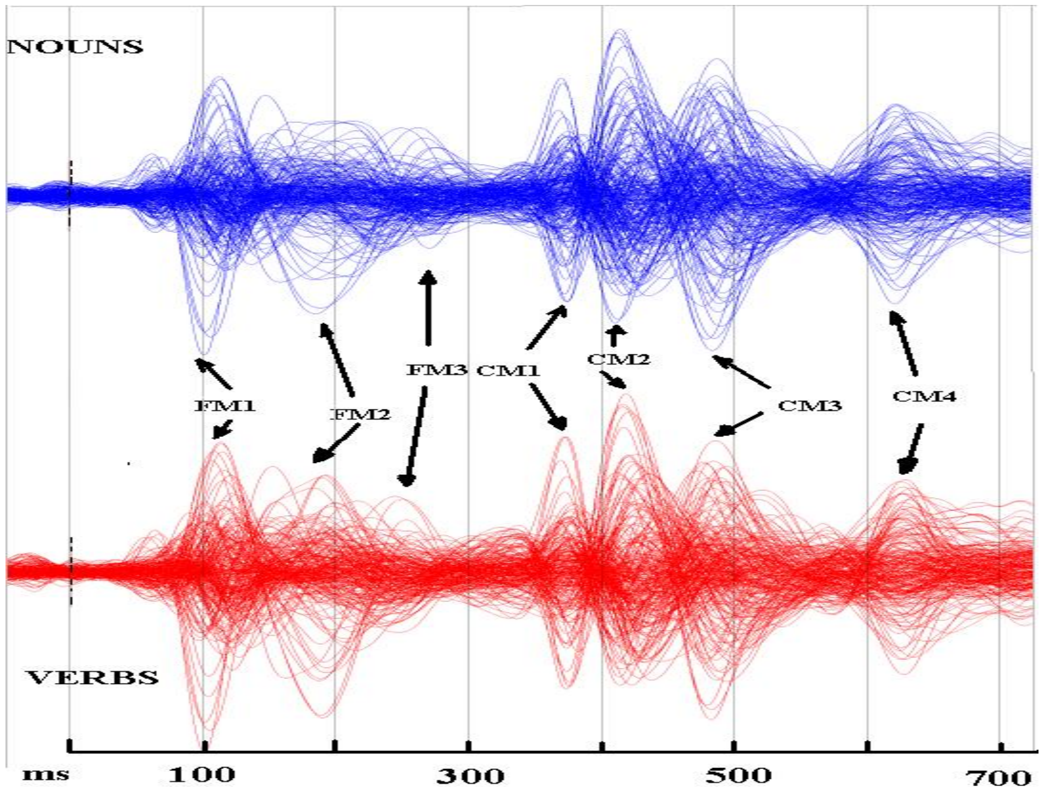

Figure 2 The response components
Averaged time-domain waveforms from all subjects illustrating the responses induced by the Noun and Verb phrases (NPs and VPs). NPs and VPs evoked the following responses: FM1, FM2 and FM3 for the Function word and CM1, CM2, CM3, and CM4 for the Content word.

The FM1 was recorded maximally between 82 and 119 ms at bilateral occipital sensors and corresponded to the first visual response. The following component, FM2, was recorded between 135 and 208 ms over similar bilateral occipito-temporal sites and corresponded to the second level of visual analysis. The third component of the function word, the FM3, was maximal between 216 and 300 ms over the fronto-temporal sensors. The content word was composed of analogous components. The CM1 was maximally recorded between 90 and 112 ms after the onset of the content word and the following component, CM2, was maximal between 126 and 162 ms; both components were recorded over similar occipito-temporal sites. CM3, the component following CM2, was documented between 197 and 227 ms over fronto-temporal sensors. The content word exhibited a fourth component, the CM4, which was maximal between 297 and 374. The center latencies of the abovementioned components for both noun and verb phrases are presented in Table 3.

	The Lexical Components	
Component	Mean Latency (ms)	
	Article	**Pronoun**
FM1	100.33 ± 18.55	98.58 ± 15.54
FM2	160.58 ± 25.2	178.75 ± 29.13
FM3	255.08 ± 29.68	258.75 ± 42.2
	Nouns	**Verbs**
CM1	101.25 ± 11.18	96.75 ± 6
CM2	144.5 ± 17.63	142.66 ± 13.98
CM3	212.5 ± 15.07	210.66 ± 14.25
CM4	341 ± 33	335.66 ± 37.89
F=function word	C=content word	

Table 3 Center latencies (mean ± standard deviation) of the brain responses for NPs and VPs in 12 participants

The identifiable noun and verb processing began and ended at approximately 100 and 620 ms, respectively. In the group analysis, no statistically significant differences in latency were found between the two grammatical classes. At the individual level, a response as early as the time interval of 40 to 50ms was detected in three of twelve subjects indicating a faster visual response to the onset of the function word. However, at the group level the difference did not reach significance and therefore, it was not analyzed any further.

3.2.2. Global field power (GFP) peak analysis

Further comparisons of the responses induced by noun and verb phrases showed no significant difference for the global field power peaks of the components. Therefore, there was no effect of an earlier or delayed latency between the two conditions. Nevertheless, statistical significant differences resulted in identifiable time windows during the processing of the verb and noun phrases. The function word of the first position homophone phrase exhibited statistical significant differences at the time intervals between 70-102 ms, 145-164 ms, and 200-237 ms after the function word onset ($p<0.05$). The statistical significant differences of the content word were identified during the following time windows: 33-47 ms, 76-98 ms, 305-320 ms and 398-403 ms after the content word onset. Figure 3 illustrates the results of the statistical analysis of the global field power averaged across all participants for NPs and VPs.

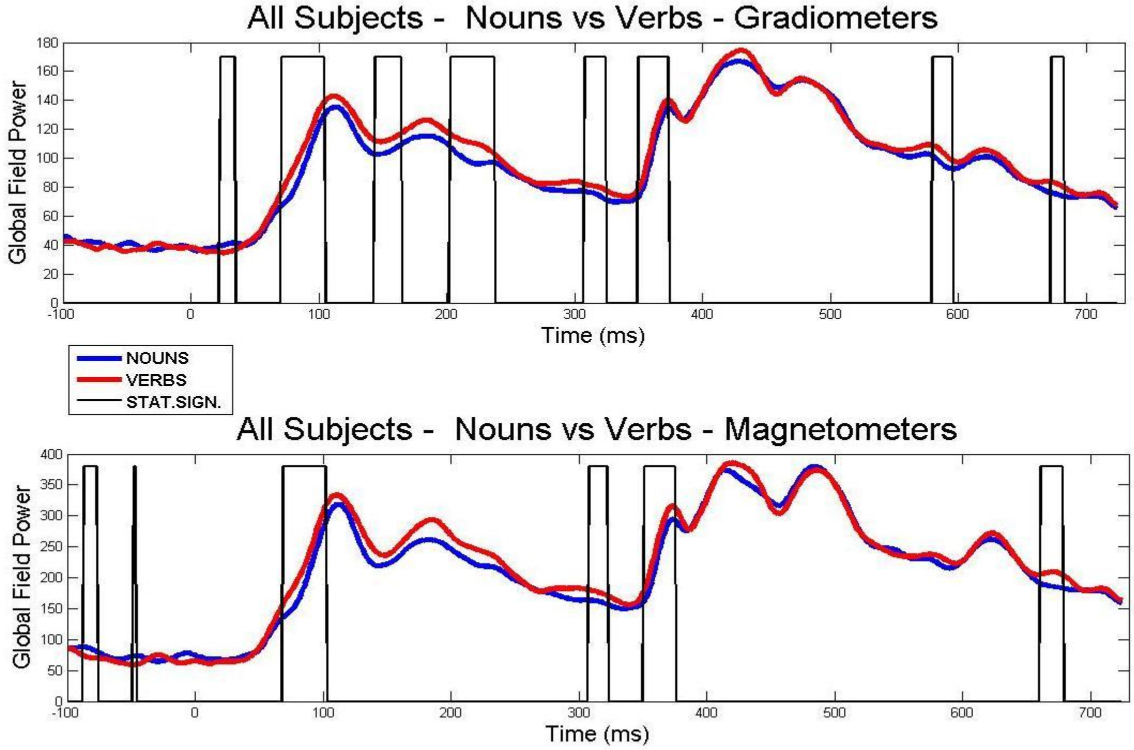

Figure 3 Global field power for the NPs and VPs from -100 to 725 ms
Global field power averaged across 12 participants for the NPs and VPs from -100 to 725 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.05). As demonstrated by the peak analyses, the GFP did not show statistically significant latency delays for any of the components.

3.2.3. Local field power (LFP) peak analysis

The analysis of the local field activity was performed at the following eight areas of interest: frontal, central, parietal and occipital sites, bilateral inferior frontal gyrus, and bilateral temporal sensors. As shown in Figure 4, the resultant statistical significant differences were consistent with the global field peak analysis. In addition, the local field analysis provided the opportunity to estimate the locus of these differences.

In particular, the significant differences at the early time window of the function word (70 to 102 ms) were located at the occipital sites, the parietal and left temporal sensors.

The difference between 200 to 237 ms of the late time window of the function word was located at the occipital, frontal, right inferior frontal gyrus and the right temporal sites. Significant differences between verbs and nouns at the late time intervals of the content word between 76-98 ms and 328-403 ms were located at the left inferior gyrus and the left temporal sensors. In addition, the difference between 305-320 ms was sited at the inferior frontal gyrus.

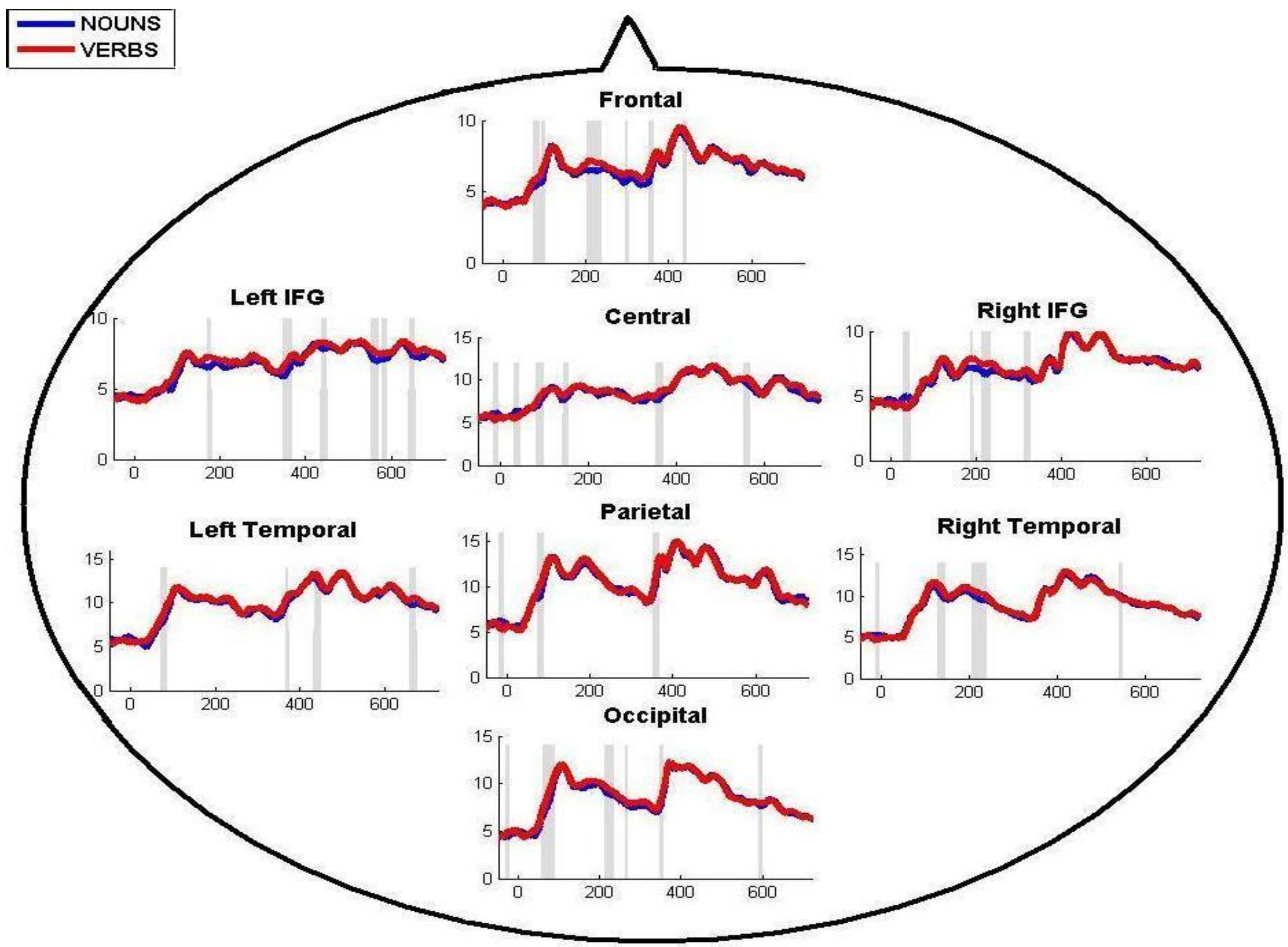

Figure 4 . Local field power activity for the NPs and VPs from -100 to 725 ms in eight areas of interest
The local field power activity averaged across 12 participants for the two grammatical classes in eight areas of interest displayed from -100 to 725ms. The grey columns indicate the statistically significant differences ($p<0.05$). The head is viewed from above with the nose pointing upwards.

3.3. The spatial course activity during silent reading of nouns and verbs

3.3.1. Minimum Norm Estimates (MNE) source analysis

The magnetic sources were individually estimated for the statistical significant differences by Minimum Norm Estimates (MNE). The MNE source localization was performed on the averages of the time windows composing the statistically significant differences that resulted by the global field peak analysis. The results of MNE source analysis showed that the cortical areas activated during verbal and nominal processing were consistent across individuals.

3.3.2 The function word

During the processing of the function word, the analysis of the global field power yielded statistical significant differences in three time windows. The cerebral topographies of these significant time intervals, as resulted by the MNE method, are as follows:

At the time window between 70 to 102 ms activation was recorded at the bilateral occipital cortex for both NPs and VPs. Statistical significant differences in areas of activation were found at the superior parietal sites as illustrated by Figure 5.

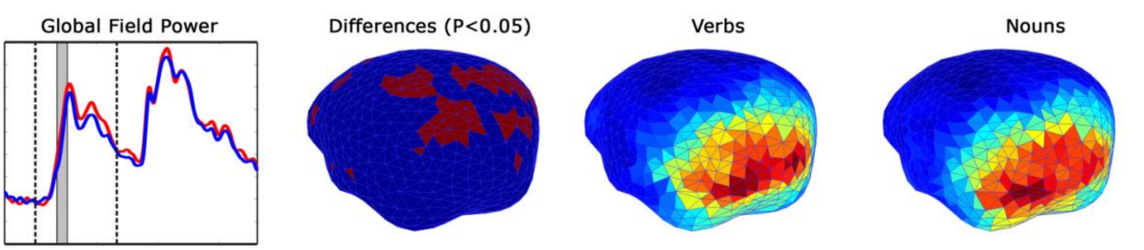

Figure 5 Statistical significant difference at the time window between 70-102 ms after the onset of the function word.

Statistical significant difference at the time window between 70-102 ms after the onset of the function word (indicated by the grey column). Left: The Global field power averaged across 12 participants for NPs (blue) and VPs (red). Right: The statistically significant differences and the corresponding areas of activation for both conditions.

The bilateral occipital activation was sustained during the time interval between 145 to 164 ms in both articles and pronouns. Further, inferior post-parietal activation was evident for the pronouns but not for the articles as shown in Figure 6 as the statistical analysis showed.

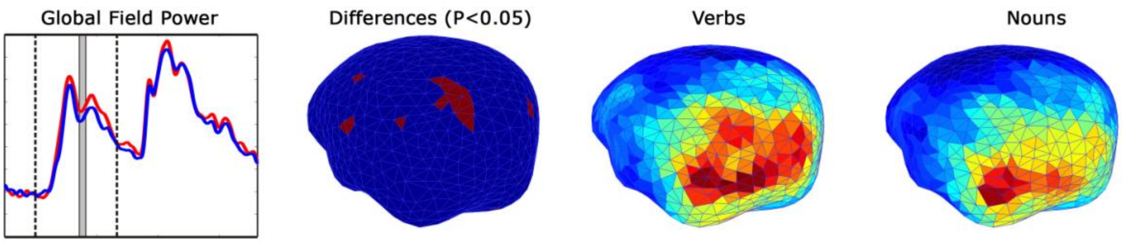

Figure 6 Statistical significant difference at the time window between 145-164 ms after the onset of the function word.
Statistical significant difference at the time window between 145-164 ms after the onset of the function word (indicated by the grey column). Left: The Global field power averaged across 12 participants for NPs (blue) and VPs (red). Right: The statistically significant differences and the corresponding areas of activation for both conditions.

The activation was further spread in the occipital sites for both function words indicating strong activation of the visual cortex during the time interval between 200 to 237 ms. The activation remained left lateralized and post-parietal. The parietal activation was significantly stronger for the articles during this time interval as opposed to the previous difference. The statistical significant differences at the superior frontal gyrus, the middle frontal gyrus (Brodmann area 10) and the superior temporal areas are depicted in Figure 7.

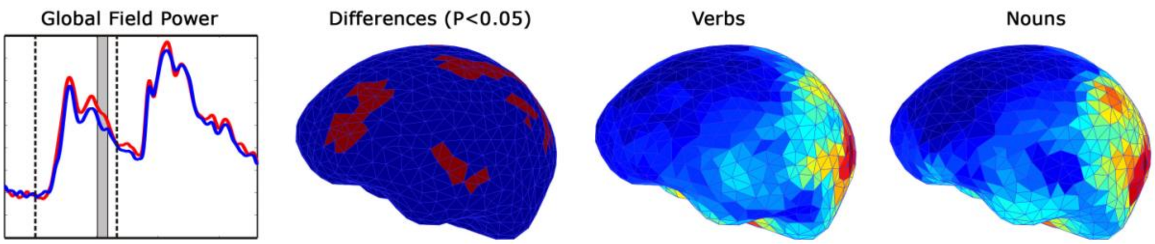

Figure 7 Statistical significant difference at the time window between 200-237 ms after the onset of the function word
Statistical significant difference at the time window between 200-237 ms after the onset of the function word (indicated by the grey column). Left: The Global field power averaged across 12 participants for NPs (blue) and VPs (red). Right: The statistically significant differences and the corresponding areas of activation for both conditions.

3.3.3 Content Word

During the significant difference between 33 to 47 ms, the cortical activation exhibited similar patterns as in the previous time window. The activity sustained lateralization to the left hemisphere, and the inferior parietal site was significantly activated by nouns as shown in Figure 8.

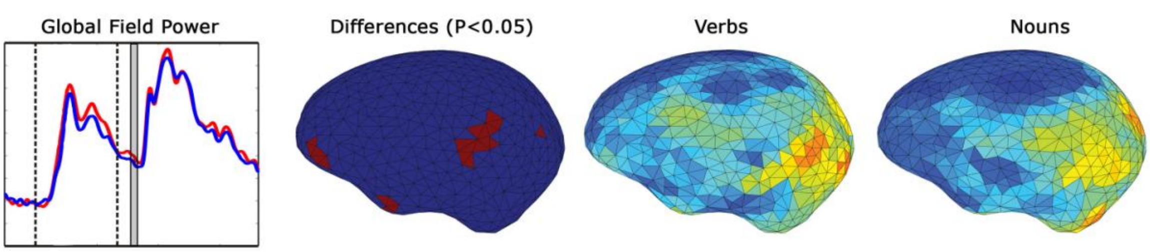

Figure 8 Statistical significant difference at the time window between 33 to 47 ms after the onset of the content word
Statistical significant difference at the time window between 33 to 47 ms after the onset of the content word (indicated by the grey column). Left: The Global field power averaged across 12 participants for NPs (blue) and VPs (red). Right: The statistically significant differences and the corresponding areas of activation for both conditions.

Between 76 to 98 ms, the differences were located at the parietal sites. The occipital sites were also strongly activated for both nouns and verbs as depicted in Figure 9.

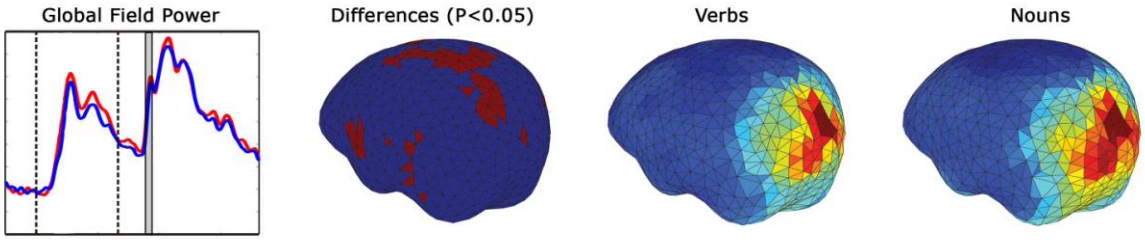

Figure 9 Statistical significant difference at the time window between 76-98 ms after the onset of the content word
Statistical significant difference at the time window between 76-98 ms after the onset of the content word (indicated by the grey column). Left: The Global field power averaged across 12 participants for NPs (blue) and VPs (red). Right: The statistically significant differences and the corresponding areas of activation for both conditions.

Similar patterns of activations between verbs and nouns are found between the last two time windows of statistical differences of the content words.

Between 305 to 320 ms significant differences of activation were located at the frontal and temporal sites. Figure 10 shows a widespread left lateralized activation with verbs displaying stronger activation at the frontal sites and nouns at the temporal areas.

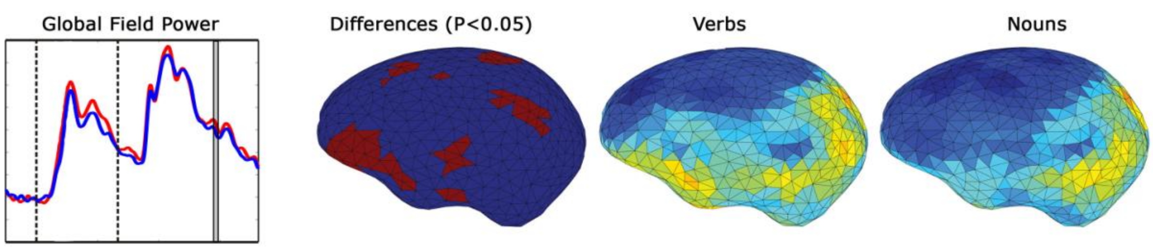

Figure 10 Statistical significant difference at the time window between 305-320 ms after the onset of the content word
Statistical significant difference at the time window between 305-320 ms after the onset of the content word (indicated by the grey column). Left: The Global field power averaged across 12 participants for NPs (blue) and VPs (red). Right: The statistically significant differences and the corresponding areas of activation for both conditions.

The time interval between 398 to 403 ms exhibited patterns of activation similar to the previous time window of significant differences. The activation remained left lateralized and specific to frontal areas during verbal processing. The inferior frontal gyrus was robustly activated by verbs exhibiting very strong intensity as depicted by Figure 11.

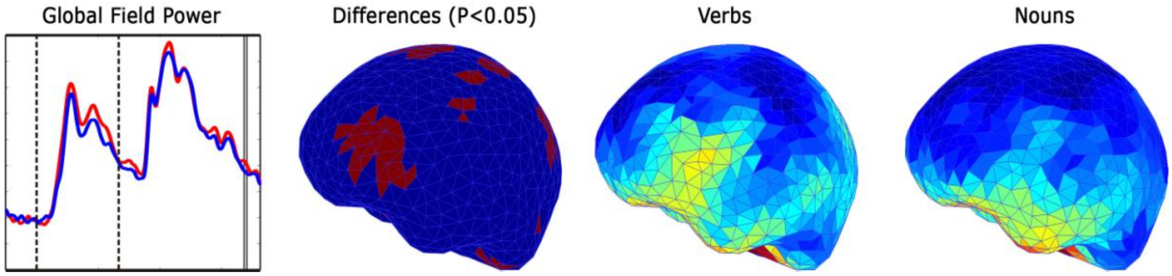

Figure 11 . Statistical significant difference at the time window between 398-403 ms after the onset of the content word

Statistical significant difference at the time window between 398-403 ms after the onset of the content word (indicated by the grey column). Left: The Global field power averaged across 12 participants for NPs (blue) and VPs (red). Right: The statistically significant differences and the corresponding areas of activation for both conditions.

The spread of the cortical activation from occipital to temporal-parietal and then fronto-temporal areas was overall similar for all subjects. However, slight variability of the timings, the intensity and the precise areas of activation was present among individual participants. The difference between noun and verb phrases was evident in all subjects as depicted by the global and the local field peak analysis, and the cerebral topographical mappings developed by the MNE.

3.4 Adaptation paradigm analysis

The comparisons in the following section are the results of the global field power peak analysis on the whole epoch (-100 to 1450 ms). We focused on the activation patterns of the first and second position homophone phrases and compared it with the designed experimental conditions. The first comparison contrasts all the trials consisting of a sequence of noun phrases with the all the trials consisting of a sequence of verb phrases.

Subsequently, we compare the trials consisting of a sequence of identical homophone phrases (Identity) with the trials consisting of a sequence of homophone phrases that belong in different grammatical categories (grammatical condition). Finally, Identity was contrasted with all the trials consisting of a sequence of homophone phrases that differ in their inflectional morphology (Morphological condition). Apparently, the analyses that follow are complex and the results of these analyses are mixed - some of them in agreement with expectations, others in disagreement.

3.4.1 All conditions: Nouns vs. Verbs (-100 to 1450 ms)

Firstly, we employed the adaptation paradigm in order to examine the differences between noun and verb phrases in an overall comparison. For this reason, we combined the two conditions of interest: the Identity (or baseline, where the two homophones were identical) and the Morphosyntactic condition (where the two homophones differ in their inflectional morphology). The two conditions were averaged across subjects and subsequently we plotted the global field peaks of the two grammatical classes against each other.

As shown in Figure 12, the resultant differences remained the same as the ones presented at the first section of the results, regarding the first position comparison. The same statistical differences were evident in the first position homophone phrase. The second position homophone phrase yielded statistical significant differences at the following time intervals: 213 to 226 after the onset of the function word and 160 to 171 after the onset of the content word.

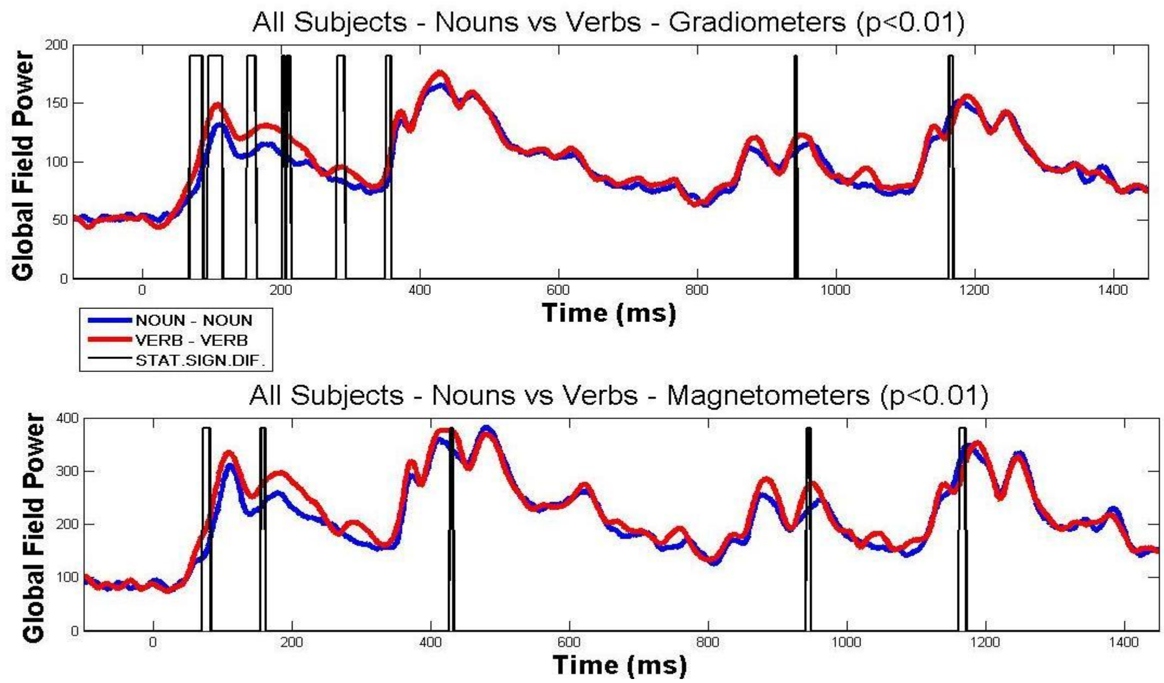

Figure 12 NPs vs All VPs: Global field power from -100 to 1450 ms
Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

3.4.2 Identity vs Grammatical Condition

In the following comparisons, we contrasted the baseline -the Identity condition, where the two homophones were identical- with the grammatical condition. The Grammatical condition was the designed experimental condition where the two homophones differed only in grammatical class (e.g. il bacio-io bacio, the kiss-i kiss). The condition consisted of instances that a verb phrase preceded a noun phrase and the reverse. The purpose of this comparison was to assess the difference between verb and noun phrases specific to the second position homophone phrase where the change of the grammatical class appeared consistently.

In the first comparison, the baseline condition contained identical verb phrases and was compared with a verb phrase preceding a noun phrase. The expectation was that the difference in activation between the two word classes would be represented by the second homophone phrase whereas the activity patterns of the phrases of the first homophone phrases would be identical.

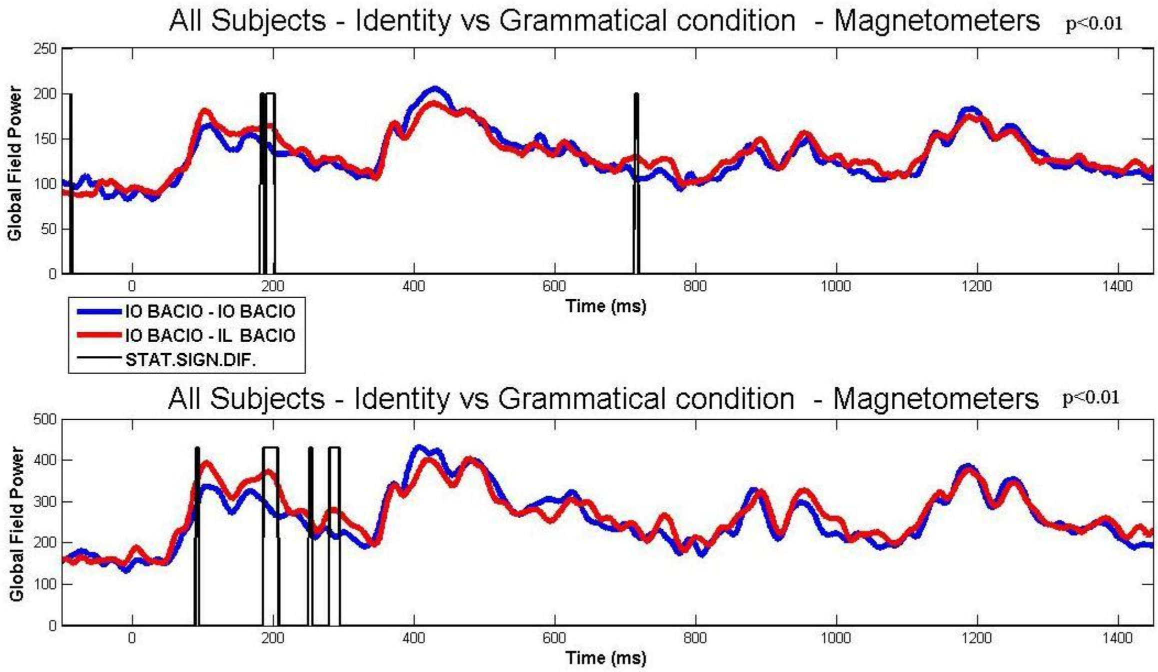

Figure 13 Global field power from -100 to 1450 ms: Identity vs Grammatical Condition: 1st person VP-1st person VP vs. 1st person VP-Singular NP.
Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

As shown in Figure 13, the differences were located in various time intervals of the first phrase; a finding that was unexpected since the two homophones belonged to the same class category. Similarly, a difference identified by the gradiometers at 440 ms after the onset of the first content word was unanticipated.

Similarly, the next comparison contrasted identical verb phrases in the baseline with a verb phrase preceding a noun phrase. It was assumed that the anticipated differentiation between the two class categories would be pronounced in the second homophone phrase. Furthermore, it was expected that the morphological operations would result in stronger intensity and/or latency. This comparison yielded the first statistical significant difference 252 ms after the onset of the first position function word in spite of both words being articles. However, this difference was not identified by the magnetometers. Another difference located 151 ms after the onset of the second position function word was also depicted by the magnetometers as shown in Figure 14.

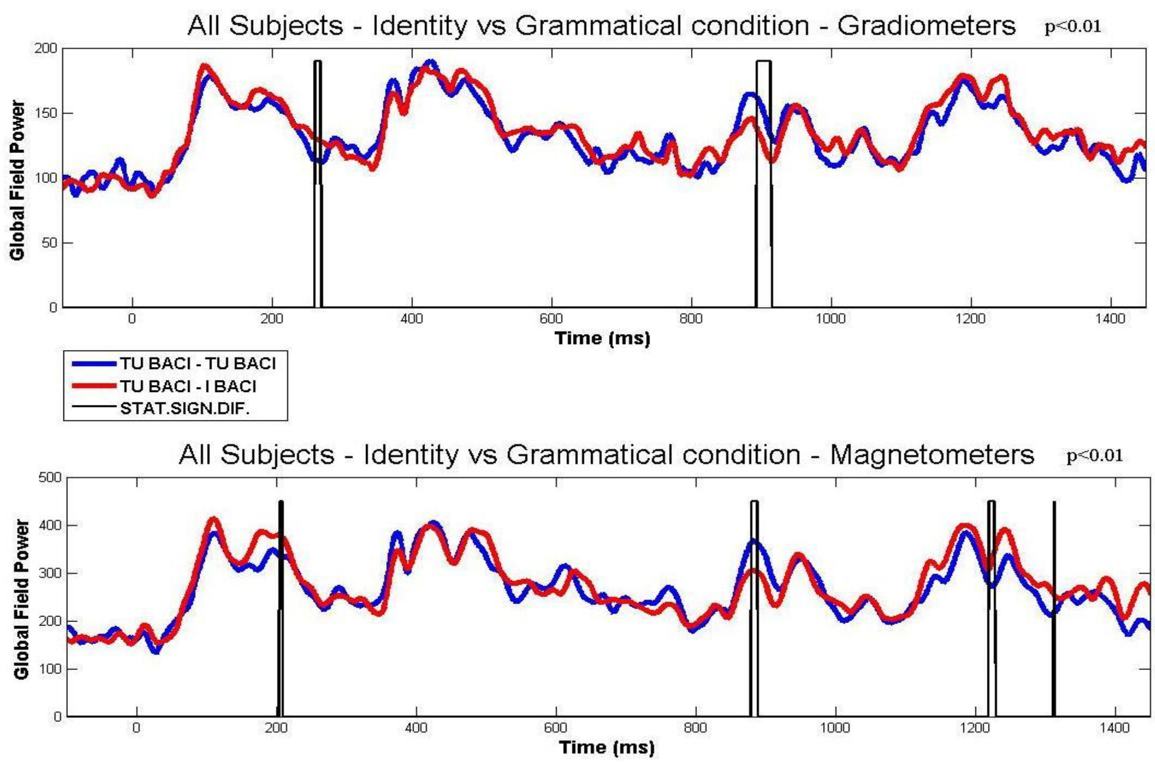

Figure 14 . Global field power from -100 to 1450 ms: Identity vs Grammatical Condition: 2nd person VP-2nd person VP vs. 2nd person VP-Plural NP.
Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

The third comparison, between the baseline and the grammatical condition, contrasted identical noun phrases against a noun phrase followed by a verb phrase. As previously assumed, we anticipated stronger activation at the late time window of the second homophone phrase due to the occurrence of morphological processes. In Figure 15, statistically significant differences were identified 104 ms after the onset of the function word and 325 ms after the onset of the content word of the first homophone phrase. The next significant difference was shown 27 ms and 215 ms after the onset of the function word of the second homophone phrase. These differences were not depicted by both gradiometers and magnetometers.

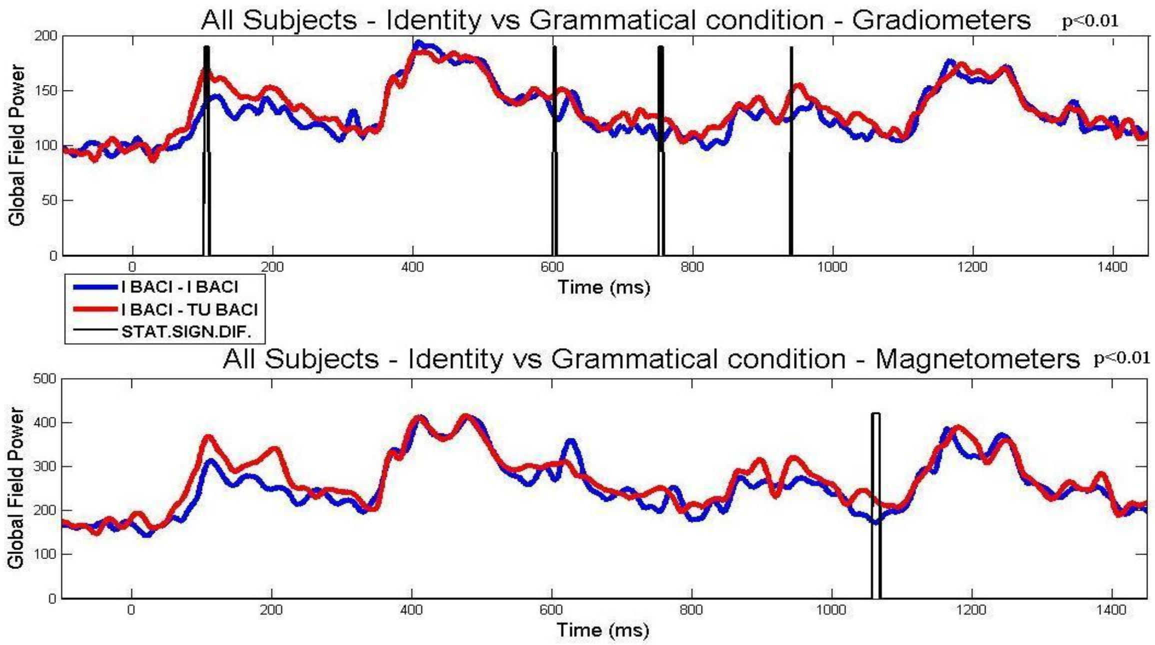

Figure 15 . Global field power from -100 to 1450 ms: Identity vs Grammatical Condition: Plural NP-Plural NP vs Plural NP-1st person VP
Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

The final comparison was between identical noun phrases and a noun phrase followed by a verb phrase.

Striking differences were found, as shown in Figure 16, at the late time window of both phrases. In the first homophone phrase, the statistical significant differences were identified 325-340 ms and 377-384 ms after the onset of the content word in both gradiometers and magnetometers. In the content word of the second homophone phrase, we observed a series of statistical significant differences at the following time intervals: 155-160 ms, 221-243 ms, 343-363 ms, and 423-428 ms. In both phrases, no statistical significant differences were detected during the processing of the early time window where the function words appeared.

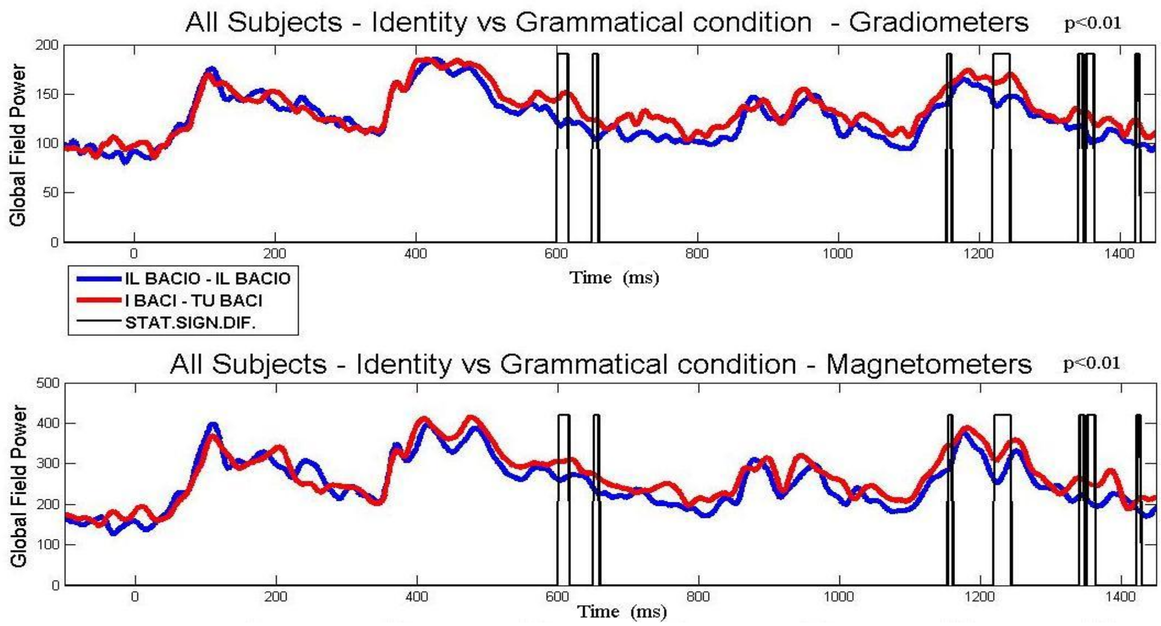

Figure 16 Global field power from -100 to 1450 ms: Identity vs Grammatical Condition: Singular NP- Singular NP vs Plural NP-2nd person VP

Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

3.4.3 Identity vs. Morphological Condition

In the following analysis, the baseline condition –namely, Identity- was contrasted with the Morphological condition where the two homophones differed either in conjugation (verbs) or in number (nouns) (e.g. il bacio-i baci, the kiss-the kisses) The purpose of these comparisons was to assess the activation patterns at the second homophone phrases where the morphological operations occurred.

In the first comparison, the Identity condition homophones were both noun phrases and singular whereas the two homophones of the morphological condition belonged to the same grammatical class but differed in morphology- a singular noun homophone was followed by a plural noun homophone.

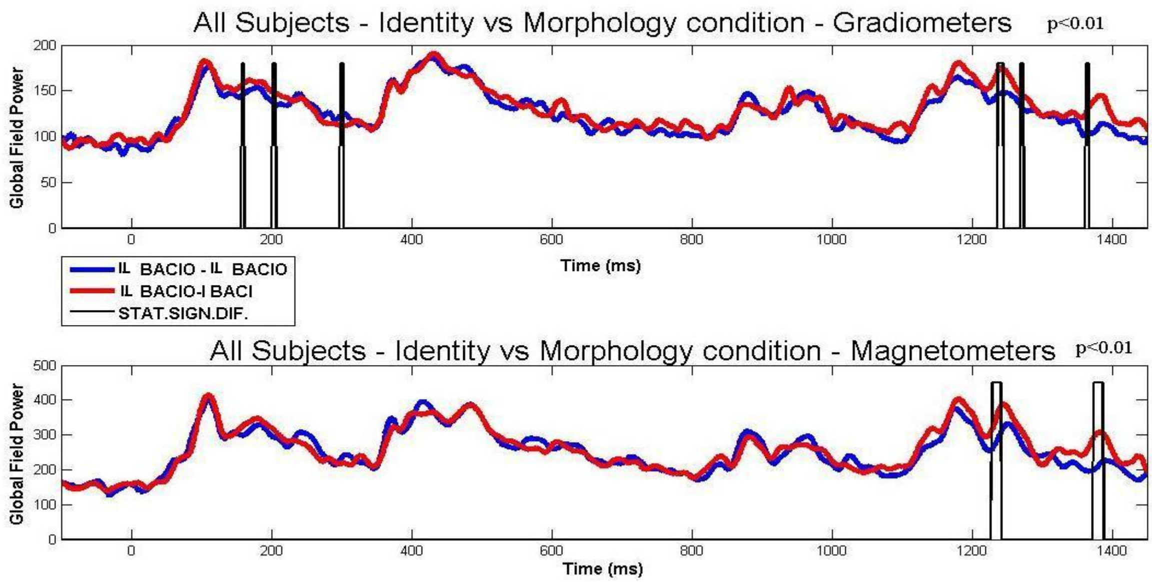

Figure 17 Global field power from -100 to 1450 ms: Identity vs. Morphological Condition: Singular NP- Singular NP vs Singular NP- Plural NP

Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences ($p<0.01$).

The statistical significant differences, as depicted in Figure 17, were 158 ms and 200 ms after the onset of the function word, and 302 ms after the onset of the content word of the first homophone phrase. However, these statistically significant differences were not identified either by the magnetometers. Between the two content words of the second homophone phrase, the analysis yielded differences at 237 ms, 270 ms and 366 ms after the onset of the content word. The differences at 237 ms and 366 ms were also identified by the magnetometers.

The next comparison was similarly structured as the previous one with the difference that the noun homophone phrases of the baseline were in plural as well as the first homophone phrase of the morphological condition. The latter one was followed by noun homophone in singular.

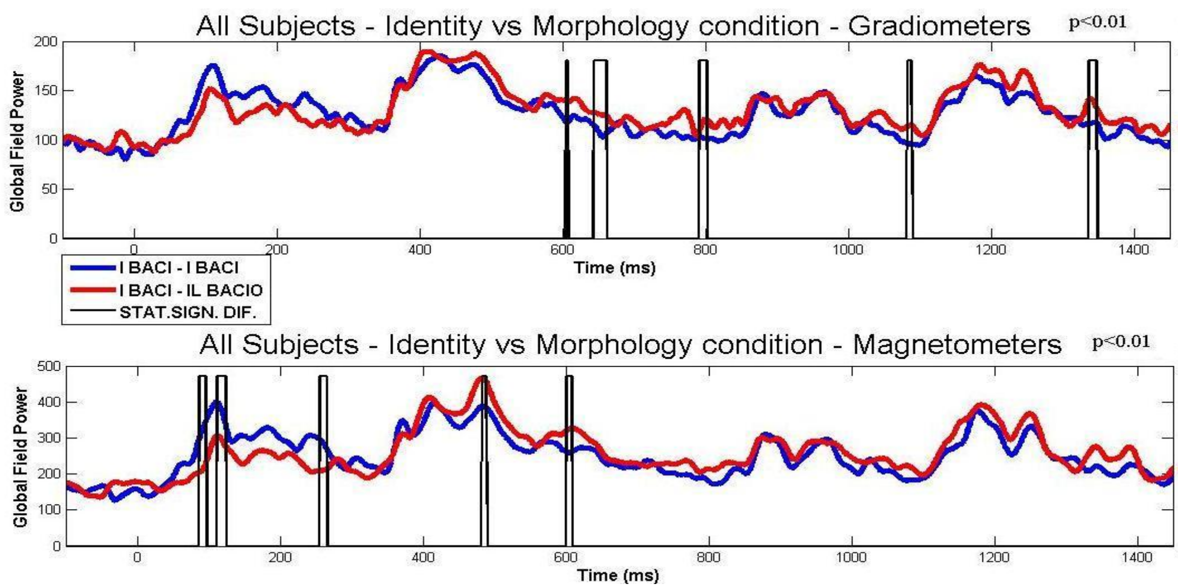

Figure 18 Global field power from -100 to 1450 ms: Identity vs. Morphological Condition: Plural NP-Plural NP vs Plural NP- Singular NP
Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

The differences, as shown in Figure 18, were mainly found at the second homophone phrase by gradiometers and at the first homophone phrase by magnetometers. The differences identified by both channels were 330 ms after the onset of the content word of the first homophone phrase. At 67 ms after the onset of the function word of the second homophone phrase, gradiometers detected a difference between the two function words.

Further differences between the second homophone phrases were found at 358 ms and 612 ms after the onset of the content word of the second homophone phrase.

In the last comparison, the baseline consisted of identical verb homophones phrases and it was contrasted with a verb phrase in the first person singular followed by a verb phrase in the second person singular, in the morphological condition.

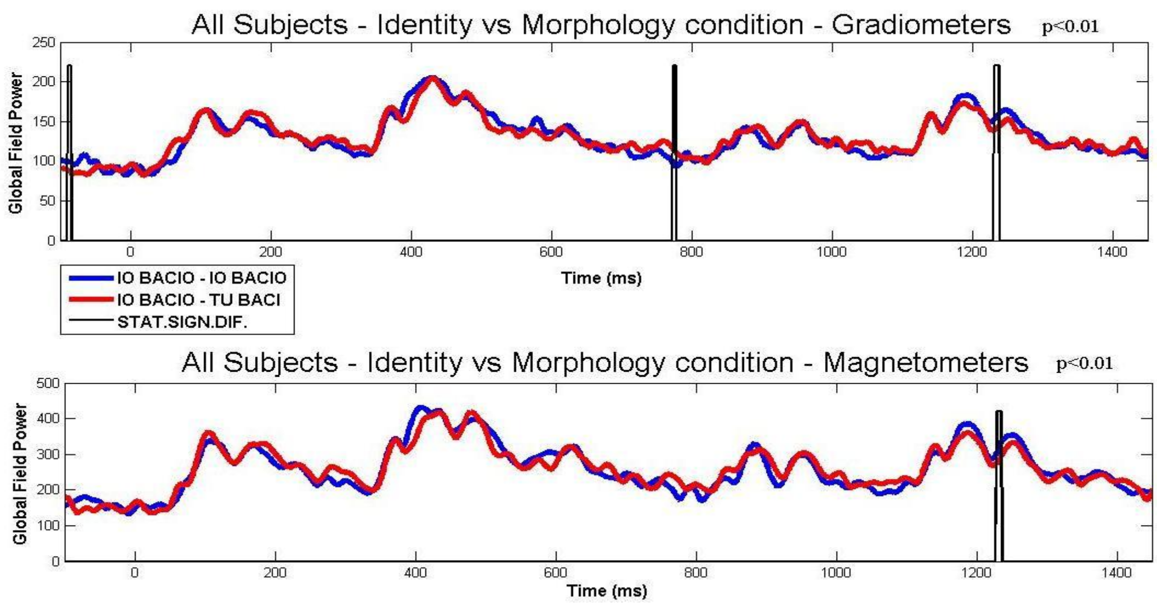

Figure 19 Global field power from -100 to 1450 ms: Identity vs. Morphological Condition: 1st person VP-1st person VP vs. 1st person VP-2nd person VP
Global field power averaged across 12 participants for the NPs and VPs from -100 to 1450 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

Statistically significant differences were evident 49 ms after the onset of the function word of the first homophone phrase and 507 ms after the onset of the content word of the second homophone phrase. The difference at 507 ms was identified by both gradiometers and magnetometers as shown in Figure 19.

Overall, the results of the comparisons among the baseline and the two conditions produced a variability of significant differences. However, they were inconclusive and difficult to interpret, especially in regards to the second homophone phrase. The possible reasons of this discrepancy will be discussed in the following chapter. Taking into account the weakness to interpret the variability of these results we did not proceed to further analysis. Regarding the Orthographic condition, it should be mentioned that the comparison with the baseline did not prove as constructive as expected and consequently, it was not developed further.

3.5 Function words:

3.5.1. Article vs. Pronoun ('IL' vs 'IO')

In Figure 2 we presented the global field power activity averaged across 12 participants for the noun and verbs phrases with duration from -100 to 725 ms. In this section, we focus only on the time interval between -100 to 300 ms of the Figure 2 that the activity patterns of the article and the pronoun is plotted. To sum up the results of the global field peak analysis and the MNE localization showed that the earliest statistically significant difference between the noun and the pronoun was recorded between 70 to 102 ms and located at the bilateral occipital cortex for both words while differences were located at the superior parietal sites. The visual cortex remained largely active between 145 to 164 ms for both articles and pronouns but the inferior post-parietal activation was stronger for the pronouns than the articles. Conversely, between 200 to 237 ms parietal activation became significantly stronger for the articles rather than the pronouns and significant differences were located at the superior frontal gyrus, the middle frontal gyrus (Brodmann area 10) and the superior temporal areas.

In addition, it is essential to take into account the values of the lexical frequencies of the two words before proceeding to the interpretation of the results. It should be mentioned that Italian is a pro-drop language, and therefore the pronoun is not required to appear with the verb in order to convey the grammatical information for the person and number. These properties are clearly expressed by the suffix of the verb. Consequently, it was expected that the pronoun would not be as frequent as the article, which on the contrary is required to appear with the noun. Indeed the value of the total lexical frequency of the pronoun 'IO' is 14598 and of the second person pronoun 'TU' is 3690 (COLFIS) while the article 'IL' has a frequency of 408845 and 28404 for the plural form 'I'. Undoubtedly, the difference is substantial and it required caution when interpreting the results.

3.5.2 Noun Articles: IL vs. LO

Furthermore, a particular feature of the Italian articles urged us to examine the activation patterns of the articles used in our stimuli in order to exclude any effects that may be due to the linguistic properties of these function words. The basis of this investigation is founded by the grammatical rule that stipulates an article should always precede the Italian noun. As discussed in the Chapter 2, there are two types of definite masculine articles in Italian: IL (Plural: I) and LO (Plural: GLI). Further, the latter is often used as a pronoun, which implies intrinsic verbal properties. However, the limited number of eligible homophone pairs –with, approximately, matching frequencies- did not allow the exclusion of the homophones preceded by the function word with the dual nature (LO). Alternatively, we compared the activity patterns of the two function words in order to examine whether they behave alike – as articles- or there is a pronounced divergence caused by the pronoun properties innate to the article LO. We extracted and then averaged all the first position homophone phrases (-100 to 300 ms) where the LO appeared. Subsequently, we extracted the same number of first position homophone phrases where the article IL occurred and then plotted the global field peak analysis, as shown in Figure 20. The two function words exhibited overlapping patterns of activation until the offset of the word. Statistical significant differences were depicted by both gradiometers and magnetometers at the time interval 263 to 281 ms ($p<0.01$). As discussed earlier the article IL has considerably higher frequency than the pronoun IO. Similarly, it should be taken into account that the two function words have different lexical frequencies. As already mentioned, the value of the total frequency of the article IL is 408845 (Plural: I has 28404) whereas the total frequency of the article LO is 3992 when the grammatical category is an article and 5343 when it is a pronoun. Likewise, the plural GLI, has a total frequency of 9775 as an article and 2581 as a pronoun. Furthermore, this article appears also as L' and it has a total lexical frequency of 28957 as an article and 2147 as a pronoun. (Bertinetto et al, 2005).

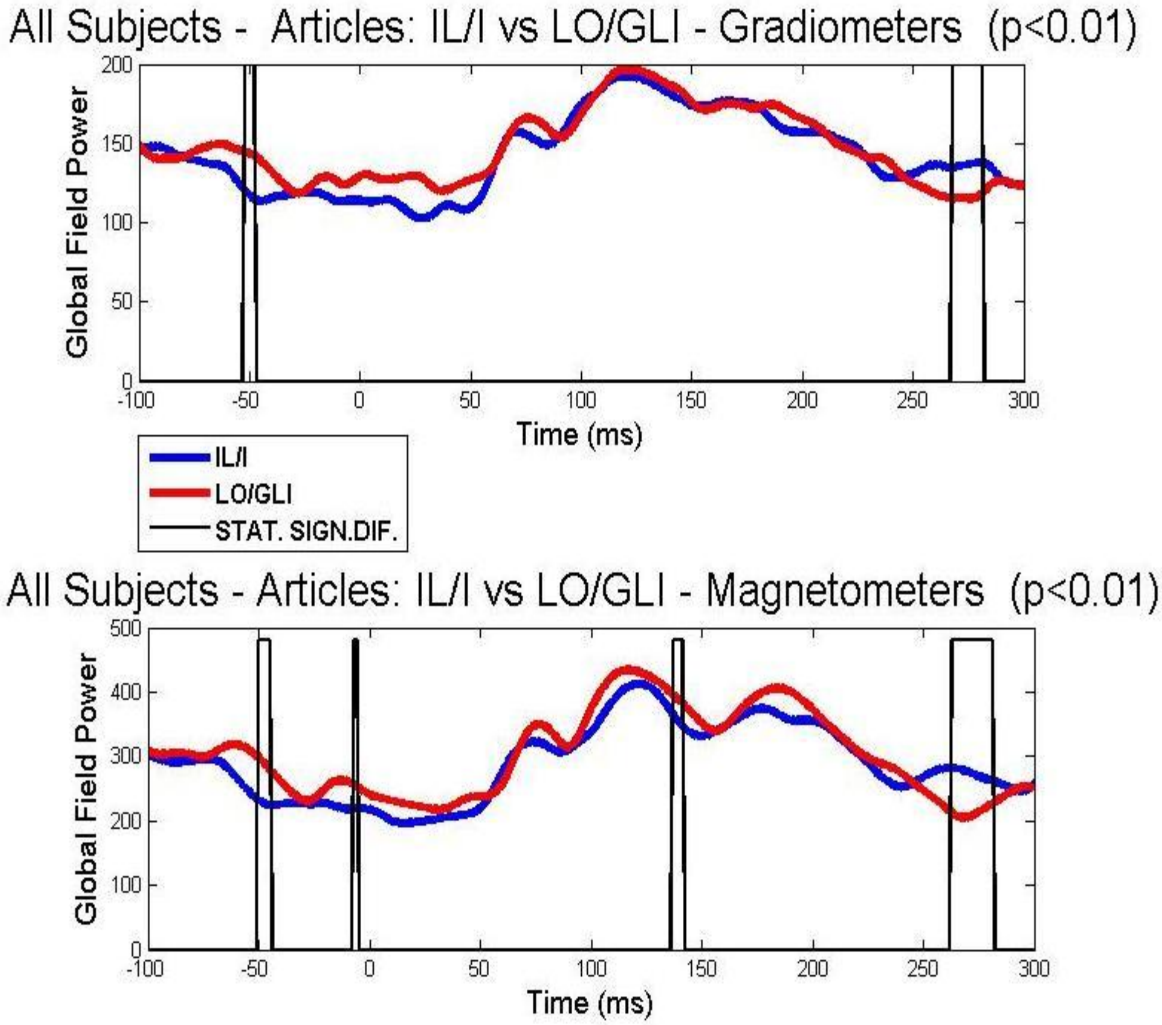

Figure 20 . Global field power for IL and LO from -100 to 300 ms
Global field power averaged across 12 participants for the two Articles: IL (Plural: I) and LO (Plural: GLI) from -100 to 300 ms as depicted by both Gradiometers (top) and Magnetometers. The columns indicate the time intervals of the statistically significant differences (p<0.01).

Subsequently we averaged the time interval between 263 to 281 ms, where the statistical significant differences were identified by the GFP analysis, and then performed the MNE source localization. The results were indicative of the location of the magnetic sources (since the calculation was performed on the average GFP of all subjects and was not previously quantified). The activation of the article ‘LO’ showed a strong source at the superior temporal gyrus whereas the article ‘IL’ exhibited a widespread activation at the inferior temporal gyrus as shown in Figure 21. An additional source was depicted at the right occipitotemporal site specific to the article 'IL'.

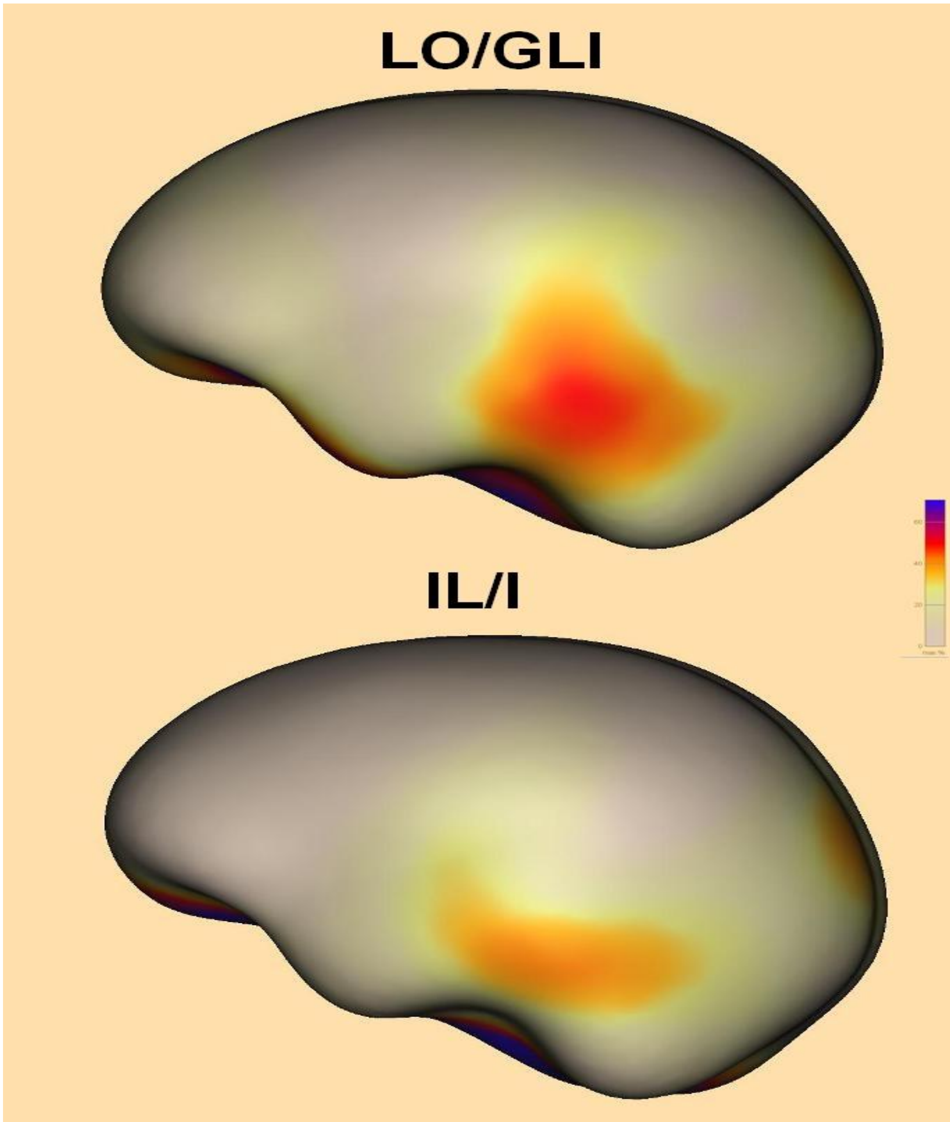

Figure 21 . MNE for IL and LO from 263 to 281 ms

The indicative averaged activation patterns as estimated by MNE across 12 participants for the two articles –IL (Plural: I) and LO (Plural: GLI)- at the time window between 263 to 281 ms (p<0.01) after the onset of the article.

3.6 Summary of Results

The present study examined the spatiotemporal differences between homophonous noun and verb phrases. The analysis divided the phrases into two words: the function and the content word.

The global field peak analyses demonstrated that both articles and pronouns induced three magnetic responses. The statistical analysis of the global field power and the consequent source localization with the MNE method did not show consistent differences in the abovementioned three responses between articles and pronouns. However, statistical significant differences were identified at the following time intervals: 70 – 102 ms, 145 – 164 ms and 200 – 237 ms after the onset of the function word. The earliest identifiable difference, 70 – 102 ms, was localized at the bilateral occipital cortex for both article and pronouns and differences were shown at the superior parietal sites. The source at the bilateral occipital cortex remained active for the time interval between 145 to 164 ms in both articles and pronouns and a strong post-parietal activation was induced by the pronouns. The later identifiable neuromagnetic difference, 200 to 237 ms, was localized at the superior frontal gyrus, the middle frontal gyrus (Brodmann area 10) and the superior temporal areas. In contrast to the former difference, the articles exhibited an intense neuromagnetic source at the parietal sites during this time window.

The analyses of the temporal and spatial course of the nouns and verbs demonstrated that both words induced four neuromagnetic sources that yielded no differences in terms of time and location. The statistical significant differences in time and location were identified at the following time windows: 33 - 47 ms, 76 - 98 ms, 305 - 320 ms and 398 -

403 ms. The earliest difference between 33 to 47 ms, exhibited activation at the same sources as the later difference of the function word discussed previously. Cortical activation was sustained at the left hemisphere, and the inferior parietal site was significantly stronger during noun processing. Between 76 to 98 ms, the magnetic source was depicted at the temporal site. Further occipital activation was evident for both nouns and verbs. The later two time windows of statistical differences of the content words exhibited similar activity patterns. Between 305 to 320 ms, two sources were located at the frontal and temporal sites: verbs demonstrated stronger activation at the frontal sites and nouns at the temporal areas. Similarly, between 398 to 403 ms the activation remained left lateralized and specific to frontal areas during verbal processing.

The analyses of the four conditions yielded a variability of results with inconsistent differences. The Orthographic condition did not prove as informative as expected and consequently the analysis focused on the comparison between the Identity versus the Morphological and Grammatical condition. Nevertheless, the results did not corroborate the findings demonstrated by the analysis of the first homophone phrase but proved barren and rambling.

In order to complete the analysis we considered necessary to examine the effect of the dual nature of the article 'LO'. Statistical significant differences between the two articles ('IL' vs. 'LO') were depicted between 263 to 281 ms. The article-pronoun 'LO' displayed a strong source at the superior temporal gyrus and the article 'IL' largely activated the inferior temporal gyrus. Additionally, the latter article showed a strong source at the right occipitotemporal site.

Chapter 4 - Discussion

4.1 Introduction

Neuropsychological lesion studies and neuroimaging data have demonstrated a variability of findings regarding the internal organization of the lexical system and specifically, noun and verb processing. The inconsistency of the findings has been attributed to the use of a variety of experimental tools (MEG, PET, fMRI) and different behavioral tasks. Furthermore, as Crepaldi et al., (2011) pointed out in a review, these discrepancies are also found in studies that employed similar methodology or tasks. The authors claimed that the inconsistency across tasks and methodology is an indicator of a discrepancy intrinsic to methodology and consequently, resulted in poor replication of the neuroimaging findings. Other explanations of the variability of neuroimaging findings speculate on the presence of confounds such as task complexity, imageability, lexical frequency or the inability to define the cognitive processes under investigation and tackle them using suitable experimental and control tasks (Crepaldi et al., 2011).

The aim of our study was to address the double dissociation debate and the abovementioned issues by investigating noun and verb homophones in Italian using MEG. For this purpose, we used a combined silent reading and lexical decision task in an experimental design that allowed us investigating the spatiotemporal underpinnings of noun and verb processing. The experiment conducted here firstly examined the temporal properties of word processing and identified the brain response components implicated in lexical processing in agreement with existing neurophysiological data. In the second step of analysis, we assessed the cortical dynamics of noun and verb phrases and revealed a neural network encompassing widespread regions of the left hemisphere and specific areas of the right one; the latter were evidently task-dependent. Therefore, as our results suggested, there are common brain regions and temporal patterns of cortical activation during the processing of both word classes. The areas that were active selectively for each word class belonged to a larger network that was engaged in both noun and verb processing. Both grammatical classes activated the occipital sites, the temporal-parietal areas and the temporal-occipital junction. The superior frontal gyrus, the middle frontal gyrus and the inferior frontal gyrus were the regions where greater activity was systematically associated with the processing of the verb phrases whereas both nouns and verbs engaged the temporal lobe. There is a clear agreement between our findings and the data from aphasiology and neuropsychology; at least partially distinct neuronal networks, which operate under a common neuromechanism of lexical processing, modulate verbal and nominal processing.

4.2 The spatiotemporal differences of the verb and noun processing

Our findings demonstrated reasonable agreement with the existing literature regarding the lexical components, their time intervals and the regions that they engage. There is, however, a controversy in the psychophysiological studies regarding the temporal properties of lexical access (Zweig & Pylkkänen, 2008), and the processes they reflect. Although we did not aim to address these issues in the current investigation, it was essential to tackle them.

In the introduction, we articulated the goal of addressing the noun-verb dissociation debate and assessing the differences of the spatial patterns in noun and verb processing. Taking advantage of the extreme temporal accuracy MEG can provide we also examined the temporal patterns of word processing. An important step of the process was to identify the peak brain responses during silent reading and to validate our results based on the majority of the ERP/MEG findings of the literature. Ultimately, it is crucial to discern the assumed stage of lexical processing based on the temporal information in order to interpret accurately the differences between the two grammatical categories. Furthermore, for our assumptions to be conclusive we merged the temporal information with the corresponding cerebral topographies and afterwards examined the ensuing implications.

A series of response components during the visual presentation of lexical stimuli has been reliably demonstrated by neurophysiological studies. In the present investigation, we identified the electromagnetic brain responses induced by the word phrases and - based on the ERP and MEG data- we linked them to the corresponding stages of lexical processing.

The spatiotemporal patterns of the verb- and noun-induced response components were essentially identical. Activation was spread from the occipital to temporoparietal and then to frontal areas underlying a neuromechanism that is assumed to comprise of the lexical processing stages such as visual processing, pre-lexical activation and lexical activation (Tarkiainen, Helenius & Hansen, 1999; Zweig & Pylkkänen, 2008). This neuronal network was common for all participants, and no differences were found specific to the time intervals or the latencies of the lexical components between noun and verb phrases.

However, the comparison of the global field activity of noun and verb phrases yielded statistically significant differences in time intervals that either preceded or followed –and in some cases, partially coincided with- the time intervals of the lexical components. These statistical differences corresponded to cerebral topographies signifying the divergence of the cortical dynamics of noun and verb phrases.

The spatiotemporal differences between noun and verb phrases are discussed in the following section in relation to the response components identified in our study and the subsequently lexical stages they represent, as postulated by the literature findings. The function and content word are analyzed in parallel to assess whether their processing is comparable. The components featured by both words of our stimulus-phrase divided into the early and late time window components; the former corresponds to the sensory analysis of the stimulus whereas the latter reflects the cognitive processing (Papanicolaou, Pazo-Alvarez & Castillo, 2006).

4.2.1 Early time window

4.2.1.1 M100

In function and content words, the earliest response components -FMI and CMI respectively- were localized in the occipital cortex, which signifies the early visual analysis of the physical stimulus. This stage reflects a low-level visual processing that is associated to all visual stimuli rather than specifically to words (Tarkiainen et al., 1999).

The differences between the two function words emerged at 70 to 102 ms after the onset. Similarly, the content words yielded a difference at 76-98 ms after the onset. The bilateral occipital cortex was engaged by both function and content words but statistical significant differences were found at the superior parietal site. The difference barely preceded the so-called M100 component, which indicates an early low-level processing of visual features and automatic pattern recognition (Tarkiainen et al., 1999). Taking into consideration the abovementioned properties and the fact that the statistical differences were located at the parietal sites, we assume that it reflects the dynamics of processing the physical features of articles and pronouns, which demands visual attention. Therefore, the parietal differences demonstrated before the stage of early visual processing suggests a low-level analysis of the physical differences of the article and pronouns rather than sensitivity to the content of the word stimulus.

However, this interpretation may sound equivocal, considering that similar parietal differences were found during the early processing of the content words, which had identical words forms –namely, homographs- in contrast to the function words. In light of this evidence, our assumption would be that an activation carryover was relayed from the function to the content word. This transfer was facilitated by the structure of the stimulus presentation in combination with the duration. The fact is that the two words were presented –and therefore, processed- as phrases and not as single words. The verbal working memory –as the involvement of parietal lobe denotes- is implicated into withholding relevant information – that is, the physical features at this stage - for the processing of the word.

In addition, function (or closed-class) words are assumed to have a different linguistic function than content (or open-class) words; the former specifies the grammatical relationships between content (or open-class) words whereas the latter has a lexical meaning (Münte, Wieringa & Weyerts, 2001; Osterhout, Allen & Mclaughlin, 2002). The implications of this distinction suggest a differentiation in the patterns of the cortical activation of the two types of word classes. Osterhout et al., (2002) asserted that evidence of diverse ERP components or incongruent distributions of components across the scalp between open-class and closed-class words would insinuate that they are 'neutrally (and, by extension, cognitively) distinct' (pg. 172). The open- and closed-word class distinction has found some support (Neville, Mills & Lawson, 1992) but the picture remains unclear. Briefly addressing this issue, we should remark that our function (or closed-class) word did not exhibit the late lexico-semantic component, the M350, as the content (or open-class) word did. However, we should firstly ensure the efficiency of the structure of the stimulus presentation before we attempt to address the implications of such a finding for the open- and closed-word class distinction debate.

In sum, differences in the early visual processing of the function word are due to the physical properties of the stimulus. Parietal activation might be due to the involvement of verbal working memory until the grammatical information is conveyed to the homophone that assumes its grammatical role from the preceding function word. In view of this, Fiebach, Maess, & Friederici, (2002), in an MEG study found no word category differences between verbs and nouns in the absence of a syntactic context; the latter consisted of the addition of a pronoun or an article as in our study. It is clear that closed-class words cannot utilize their lexical function when presented in isolation and the impact of this implication would be greater for homophones.

4.2.1.2 M170

Bilateral occipito-temporal sources were observed for the second response components of both words -namely FM2 and CM2- suggesting preliminary language processing. This component, referred conventionally as M170, has been associated with letter string processing (Tarkianien et al., 1999) and face stimuli (Liu et al., 2002;). Tarkiannen et al., (1999) identified greater activity in the left occipitotemporal areas for letter strings than for symbol strings. These findings were substantiated by additional studies that revealed a link between letter string processing and the left inferior posterior temporal regions (Cohen, Dehaene & Naccache, 2000). More recently, Zweig & Pylkkänen, (2008) determined that M170 activity is also sensitive to morphemes and concluded that this complexity effect suggested a prelexical interpretation of the M170 component. However, an additional body of psychophysiological evidence has proposed that M170 is further implicated in the lexical frequency effect where timing varied with word length (Seteno, Rayner & Posner, 1998; Assadollahi & Pulvermüller, 2003). Specifically, Assadollahi & Pulvermüller (2003) showed in a MEG study, the frequency effect occurred around 150ms in short words but around 200ms in long words.

Cornelissen, Kringelbach & Ellis, (2009) pointed out that the abovementioned findings belong to a series of electrophysiological studies that suggest an interaction between visual and linguistics variables during an early time window processing. For example, Pulvermüller, (2001) suggested that brain activity could be affected by lexico-semantic variables as early as 160ms. In the same line of evidence, Hauk, Davis & Ford, (2006) proposed that there may be an early involvement of the left frontal areas in semantic processing but the study did not exhibit robust anatomical data. More recently, Dikker, Rabagliati, & Pylkkänen, (2008) identified a sensory response of closed-class words when presented in a mismatched syntactic context only after 125ms. Similarly, Cornelissen et al., (2009) found the activation of the left inferior frontal gyrus as early as

130ms, in a passive viewing paradigm. This would imply syntactic cues are processed concurrently with the sensory cues and therefore, impinge on the occipital areas.

Our analysis yielded differences between articles and pronouns preceding by few milliseconds the well-studied M170. Specifically at the time interval between 145-164 ms, the bilateral occipital activation was sustained for both function words but the inferior parietal area was strongly activated for the pronouns but not for the articles. In line with the abovementioned findings, the differences exhibited before the M170 mark the pre-lexical visual processing of the pronoun that possibly reflects its low values of lexical frequency. In addition, the involvement of the parietal lobe becomes specific to pronouns as processing evolves from the low-level features analysis to preliminary language processing. Nonetheless, the content word did not exhibit corresponding differences challenging the accounts that consider M170 sensitive to morphologically complex words.

The findings of the present investigation cannot robustly claim any interaction between visual and linguistics factors in an early time window of processing even if related to lexical frequency. To begin with, the comparison of the duration of the lexical components evoked by the function and the content words did not verify the abovementioned interaction between lexical frequency and word length. The function words consist of articles and pronouns that are monosyllabic and own apparently higher lexical frequencies than the content words. However, the onset and offset of the lexical components of both function and content words exhibited comparable time intervals as shown in Table 1 in Chapter 3. It would be more plausible to assume that the visual analysis of letter strings resulted in a consequential physiological response depending on the visual familiarity of the item under processing.

4.2.2 Late time window

4.2.2.1 M250

In the late time window, FM3 and CM3, the third response components were localized at the frontal and temporal cortices reflecting pre-lexical processing as postulated by a number of studies (Pylkkänen & Marantz, 2003; Meng, Xiang & Rose, 2010.; Xiang & Xiao, 2009). The comparison of the function words yielded statistical differences slightly preceding this component at the time interval between 200-237 ms.

The topographical pattern was reversed as opposed to the previous identifiable statistical difference: the parietal activation was significantly stronger for the articles but not for the pronouns. Considering the temporal proximity of the difference to the M250, we assume it reflects the sublexical processing of the phonotactic properties (Pylkkänen, Stringfellow & Marantz, 2002) of the articles. Further statistically significant differences between the two function words were located at the superior frontal gyrus, the middle frontal gyrus and the superior temporal areas indicating the dynamics of prelexical processing (Pylkkänen & Marantz, 2003).

Furthermore, the comparison within the function words - the article 'IL' and the article/pronoun 'LO'- exhibited a difference close to the offset of the word, 263 to 281 ms. The left inferior temporal gyrus and the right occipitotemporal site was evidently more active for the highly frequent word, 'IL', whereas 'LO' exhibited a source at the superior temporal gyrus. This difference is indicative of a frequency effect, as expected, but in a later time window than what the literature postulates (e.g. Assadollahi & Pulvermüller, 2001; Seteno et al., 1998). The 'delayed' frequency effect could be attributed to the intrinsic features of the article-pronoun 'LO'; the cumulative effect of the low frequency and the inherent verbal properties it assumes.

4.2.2.2 M350

As mentioned already, only the content word exhibited a fourth component, the CM4, which is often referred as M350. The M 350 is claimed to depict high-level lexical activation and semantic processing (Pylkkänen et al., 2002; Helenius et al., 1998) and also is suggested to reflect the frequency-effect of open-class words (Embick, Hackl & Schaeffer, 2001).

However, the identifiable differences between the nouns and verbs were located at the frontal and temporal sites during 305 to 320 ms after the onset, preceding the M350. More specifically, verbs showed a stronger activation at the frontal sites and nouns at the temporal areas. This difference of activation was more pronounced during 398 to 403 ms where the inferior frontal gyrus was strongly activated by verbs whereas the noun processing showed a widespread activity at the inferior temporal sites. This difference at the late time window reflecting cognitive processing allows us to argue for the divergence of verbal and nominal processing. On this view, the inferior frontal component would be an expression of the morphosyntactic operations over verbal processing. As such, it would license the assumption for partially distinct networks of processing for verbal and nominal morphology. Further, it justifies the design of the experimental protocol that consists of a number of conditions that tackle the morphosyntactic processes and it substantiates the assumption that specific areas of activations will manifest morphosyntactic processes. These results essentially agree with the functional distinction between verbs and nouns, and their -partially- separate neural representations in a nevertheless common, neuromechanism.

Interestingly, the content words exhibited a spatial difference during the first 33-47 ms after the onset. The topographical mappings showed left lateralized activity and strong activation at the inferior parietal region during noun processing. However, these differences are attributed to the carryover of activity from the previous frame containing the function word. The areas of activation where the differences were located are ostensibly a continuum of the patterns of activation identified during the last lexical component of the function word. Furthermore, 33 ms after the onset is considered far too early for the physical stimulus to be processed by the visual network. Consequently, it is rational to attribute these differences to a remnant of activation from the preceding function word.

4.3 The Parietal lobe activation

Overall, our results agree with existing literature findings of aphasiological data and neurophysiological evidence. We identified a common neuromechanism where verbs and nouns are processed in partially distinct neural networks as demonstrated by a number of neuropsychological studies (e.g. Shapiro & Caramazza, 2003b; Tsapkini et al., 2002; Caramazza & Hillis, 1991; Damasio & Tranel, 1993). Furthermore, the main differences between nouns and verbs were depicted in the late time window where the cognitive processing is assumed to take place. We showed that while nominal processing is specific to temporal sites, verbs engaged parts of the temporal network but mainly the frontal areas.

One of the interesting results of our investigation is the implication of the parietal area in the processing differences between the two grammatical categories. As shown earlier, parietal activation was not specific to one grammatical category but it varied during word processing. During the processing of the function word, parietal activation was more intense and occurred earlier for the pronouns. The presence of parietal activation throughout the temporal window indicates the working of Verbal Working Memory (VWM). We can assume that the pronouns or verbs are maintained in the verbal working memory for consequent elaboration, which does not happen as early with nominal processing. The reason could be that the morpho-syntactical weight of the verbal properties consists of multiple operations that are specific to verbal processing. Therefore, nominal processing is faster, less intense and does not require the extended working of VWM. Consequently, the activation of the parietal lobe during verbal processing is justified by neuroimaging evidence on healthy populations and lesion studies that claimed that the left parietal cortex reflects processing of the verbal short-term storage (Jonides, Schumacher & Smith, 1998; Paulesu, Frith & Frackowiak, 1993). Berlinger et al., (2008) found bilateral premotor and superior parietal activation in relation to verb processing and concluded that the representation of verbs may depend heavily on action-oriented (visuo-) spatial knowledge. In addition, Sahin and the others identified differences between nouns and verbs in the intraparietal sulcus (IPS) and assumed the possibility that the IPS may be implicated in inflectional processing. The authors supported their rationale based on the fact that both noun and verbs mark number and the IPS has been implicated in several cognitive functions such as number cognition (Dehaene, Tzourio & Frak,, 1996).

On the other hand, other imaging studies have shown an unclear picture of the right parietal region in relation to verbal working memory tasks. A review of 275 PET and fMRI studies (Cabeza & Nyberg, 2000) observed little involvement of the parietal sites in language tasks or semantic memory retrieval. In regards to our findings, taking into consideration the structure of our task and the patterns of activation identified, we tend to infer that the major implication of the parietal lobe here is mediating task-related visual attention as it seems to be general to all tasks (Jovicich, Peters & Koch, 2001).

Furthermore, during the early visual analysis of the function word, we identified differences between the pronoun and the article in the parietal area but we cannot assertively claim which function word (article or pronoun) activated the parietal areas more intensely. However, considering that 45 ms later and just before the M170, parietal activation became specific to the processing of pronouns we could entertain the possibility that it is the consequential continuum of the topographically ambiguous former difference. The pattern changed in less than 100 ms later – verging on the M250- suggestive of the processing of sublexical phonotactic properties of the articles as mentioned earlier.

As we discussed above, the earliest difference exhibited after the onset of the content word is regarded as the continuum of the processing of the function word. As the cerebral topography justified this assumption, the parietal activation remained specific to the article processing. In a similar fashion as in the function word, differences were depicted at the parietal lobe during the early visual analysis of the content word but the specific dynamics were still not possible to identify.

The remarkable finding is that the content words did not exhibit any difference close on the M170 at the parietal region as the function words did. Lastly, the parietal area did not show any involvement during the late cognitive processing of the content word.

Overall, these findings indicate that the implication of the parietal regions occurred in a task-dependent manner mediating the verbal short-term storage.

4.4 Comparison with other findings

The variability of neuroimaging findings regarding the noun and verb dissociation has been repeatedly addressed by research and many attempts have not fully succeeded to elucidate the matter. Seemingly, the methodology and the variability of tasks have been considered the main causes of this discrepancy. Nonetheless, a number of neuroimaging reports have identified the cerebral correlates underpinning the verbal and nominal processing and the results suggested that they might differ in their patterns of cortical activation.

In the present investigation, with a silent reading task constructed to tackle basic lexical processing, the inferior prefrontal cortex was activated only for the verb trials whereas both nouns and verbs engaged the temporal sites. Temporal activation, however, was not as widespread or intense for the verbs as for the nouns. Undoubtedly, the inferior prefrontal cortex is central to the distinction between nouns and verbs. Furthermore, the fact that prefrontal activation was evident during the late cognitive processing reflects the crucial role that it assumes in morphological operations. Previous ERP and MEG studies agree on the differential neural representation of verbal and nominal processing as reflected by the distinct brain waveforms induced by verbs and nouns (e.g. Koenig & Lehmann, 1996; Pulvermüller et al., 1996; 1999; Xiang & Xiao, 2009; Fiebach et al., 2002). MEG studies have further provided spatial information depicting the classic difference that research predicts: distinct or stronger activity in the temporal lobe for nouns and in the IFG for verbs. Our results converge with other findings such as Shapiro, Moo & Caramazza (2006) – an fMRI study- that identified the left prefrontal and the left superior parietal cortices as verb-selective areas whereas nominal processing showed greater temporal activation. Our findings, however, extended the verb-selective regions to the temporal areas. Similarly to Shapiro et al., (2001; 2003; 2006) and Tyler, Bright & Fletcher, (2004) our stimuli contained of morphological inflections (such as the noun plural and the verb conjugation) to ascertain access to grammatical category information. Further, the nouns and verbs were presented in the context of phrases, as in Shapiro & Caramazza, (2003b), to facilitate morphological processing since the homophones out of context are class-ambiguous. From the linguistic point of view, the verb phrase is a syntactic construction and the noun phrase is not. This critical difference is considered to entail the provenance of the divergence between nouns and verbs. However, as Shapiro et al., (2006) pointed out, the morpho-syntactic operations 'stem directly from the intrinsic grammatical properties' of the two classes. Tyler et al., (2004) used a semantic categorization task of inflected words without syntactic context to identify the main noun-verb difference in the left inferior frontal gyrus, which is in agreement with the results of the current study. In line with the argument of Shapiro et al., (2006), Tyler et al., (2004) assumed the verb activations reflected morphological processing mainly attributed to its inflection, which encompasses stronger grammatical aspects for verbs than nouns. Similar conclusions were reached in two rTMS studies that employed cued elicitation tasks; Shapiro et al., (2001) found increased reaction times following rTMS to the left anterior midfrontal gyrus, compared to sham stimulation, only for verb but not for the noun production. Cappelletti, Fregni & Shapiro, (2008) substantiated and further extended these results.

Aside from the frontal areas, the present results exhibited a difference in the parietal region similarly to Sahin et al., (2006). As the difference was not specific to one grammatical category and moreover there are several cognitive functions attributed to parietal lobe we assumed -in agreement with Sahin et al., (2006)- that parietal involvement reflected task-related visual attention.

On the other hand, the present findings diverge from PET data such as those of Tyler et al., (2001), Perani et al., (1999) , Warburton et al., (1996) and the ER-fMRI study of Sahin et al., (2006) who found areas that were more active for verbs but not for nouns. Taken together, noun and verb processing activated the same set of areas suggesting no difference as a function of word class. The tasks employed in these set of studies varied; seemingly lexical decision, semantic categorization and word generation tasks activated the same regions for nouns and verbs.

Shapiro et al., (2006) used an oral production task arguing that on-line access to grammatical category information accurately pinpoints the factual verb-noun differences. In the current study, a silent reading task was preferred mainly to avoid signal noises. We argue that the cognitive processes involved in reading - silent or aloud- are not just a subset of the inflectional processing (Sahin et al., 2006). For the purposes of this study, the silent reading task was considered appropriate to utilize the MEG assets and applicable to access the grammatical class information.

An additional issue to consider is the findings of other studies that utilized homophonous words for the investigation of noun-verb differences. In an ERP study, Federmeier et al., (2000) found a left, lateral positivity over the frontal and prefrontal sensor, specific to unambiguous verbs. The word class-ambiguous (or homophonous) verbs did not exhibit the same pattern leading to the inference that ambiguous items own a different representation from the unambiguous items. The authors concluded that word class properties 'do not reside in a neural representation' (pg. 2565) but they are modulated by the nature and context of the stimulus. Harris, Randall & Moss, (2005) in a behavioral design found slower reaction times for homophonous verbs than homophonous nouns, which was attributed to the lower imageability of the former and they concluded that the noun-verb distinction is not specific to class properties. However, the selected homophones were verbs and nouns that targeted the elicitation of action and object naming respectively, which did not necessarily share the same meaning. Likewise, Tranel et al., (2005) targeted the distinction between action and object processing using homonyms, in a PET study. While homonymous object-nouns activated the left inferotemporal (IT) and the left frontal opercular regions (FO), the non-homonymous object-nouns activated only the left IT. IT and FO, and the left posterior middle temporal regions showed activation for both homonymous and the non-homonymous action-verbs. The leading conclusion was that 'noun-verb' differences might be unreliable when assessed with homophonous stimuli.

In the present study, homophonous stimuli were considered suitable to isolate the grammatical class effect. We reason that homophones will not exhibit the same activation considering the information provided by the function words. For this reason, the syntactic context was crucial variable for the experimental design. Furthermore, we are rather concerned with the lexical grammatical representations of the homophones than the top-down modulation of word class processing.

4.5 Theoretical accounts on the noun-verb dissociation

Clinical reports have been consistent demonstrating that brain lesions can cause impairments in verb processing while noun processing remains intact, or vice versa (Bates et al., 1991; Caramazza & Hillis, 1991, Damasio & Tranel, 1993; Hillis & Caramazza, 2004). While the neural fundamentals involved in this double dissociation are yet tentative, the fact is that lesions to the left frontal cortex result in verb impairments while damage to left temporal lobe causes nouns deficits. Simultaneously, there is an ongoing debate regarding these differences and the dynamics they reflect: the categories themselves, their meanings or their properties (Caramazza & Shapiro, 2004; Shapiro et al., 2001; Perani et al., 1999; Pulvermüller et al., 1999).

One of the most common interpretations of the noun-verb dissociation argues that noun and verb representations as grammatical categories activate separate cortical networks (Shapiro & Caramazza, 2003a). Nouns and verbs occupy different grammatical roles in the sentential construction consistently reflected by the difficulties of agrammatic patients to produce verbs. Other accounts attribute the differences between nouns and verbs to their different lexical functions (Shapiro & Caramazza, 2003b). Each word class owns specific moprhosyntactic operations and therefore, separate lexical representations. On other accounts, the divergence in the processing of the two word classes results from their semantic representations; nouns are inherently more concrete than verbs (Neininger & Pulvermüller, 2001) and differences between the two categories consist of a collective effect of concreteness, imageability, or of all the dimensions relevant to lexical meaning (Caramazza & Shapiro, 2007). For example, Tranel et al., (2005) suggested that homonymous words are processed in different neural regions depending on their prominent semantic interpretation rather than their grammatical class – nonetheless, they did not exclude the influential role of the latter. However, such a distinction is not absolute since there are verbs that refer to abstract events and nouns that refer to actions as Shapiro et al., (2006) pointed out. The stimuli used in the present study consisted of homonyms that shared the same spelling, pronunciation and, in their majority, meaning. We attempted to control for the lexical properties of the stimuli by matching the frequency of the homophonous pairs. As far as the semantic properties are concerned, the semantic relationship between nouns and verbs is not homogeneous. Our set of homophones included items that fall into the action–object/tool distinction such as *'martello'* ('hammer') but also pairs that signified an event or the end-product of an action such as *'bacio'* ('kiss'). Therefore, we cannot conclusively attribute the resultant patterns of activation to semantic idiosyncrasies of the two representations. The presence of a syntactic context in our experiment enhances the emergence of the grammatical properties of the homophonous words, which allowed us to discuss our results in terms of grammatical class. As discussed earlier, other studies have acknowledged the presence of a context as a critical factor for the differences between nouns and verbs to surface

(Fedrmeirer et al., 2000; Fiebach et al., 2002). At the same time, the issue extends to the link between the variety of the tasks and the variability of the findings. The noun and verb activity patterns considerably diverge in studies employing different tasks. For example, Berlingeri et al., (2008) used noun and verb retrieval to address the differences in their processing and concluded that the activation exhibited in the left inferior frontal gyrus and in the left insula suggested ' higher cognitive demands of the task rather than verb specific lexical or lexical-semantic processing' (pg. 551). Although this is a frequent pattern in the neuroimaging literature, it is not however the rule. Perani et al., (1999) used a lexical decision task and identified the crucial role of the inferior frontal gyrus for verb processing. Similarly, Damasio and Tranel (1993) found that the left frontal cortex is prominently engaged in verb processing and identified differential neural networks activated during noun and verb retrieval. Corina et al., (2005) reached similar conclusions via cortical stimulation mapping during a noun and verb naming task.

4.6 Comments on the adaptation paradigm design

As we showed at the Results chapter, the comparison among the four conditions of the experimental design yielded variable results. The purpose of the different experimental conditions was to assist the investigation into the detailed description of the activation patterns between noun and verb phrases and further deepen the scope of the original research question.

In combination with the experimental paradigm of the adaptation analysis, it was expected that the experimental conditions would pinpoint the following variables: class categories and inflection (number and conjugation). Further, we designed an orthographical condition to facilitate activity induced by orthographic similarity. The target items consistently occupied the second position of the trial based on a rationale similar to the foundation of the priming paradigm. The aim was that the subtraction between the baseline (Identity condition) and the experimental conditions would result into the activation patterns under investigation. However, the findings resulted by this type of analysis were inconclusive. The subtraction method was not suitable for our raw data and the resultant patterns could not be reliably interpreted.

The reason behind this incongruity may have variable causes. Considering the available data, we cannot attribute this discrepancy to an explicit cause and therefore, we are limited to assumptions. A possible explanation implicates the combination of the adaptation paradigm and the number of trials. The comparisons based on the combinations of the experimental conditions consisted of fewer trials than the main comparison between all verbs and all nouns phrases. The small number of trials may have deteriorated the strength of the signal. An additional potential reason involves the actual presentation of the stimuli. The stimulus was presented serially and visually without interstimulus intervals. It is possible that the absence of interstimulus intervals resulted into a carryover of activation from one frame to the next during the whole trial; that is, from the first position phrase to the second one and from the function word to the content word. This possibility could be supported by the fact that the activations patterns of the second position phrase are consistent neither with each other nor with the first position phrase -even when the exact same phrases are processed. Further, the absence of the fourth component during the processing of the function word could be considered as supporting evidence of the activity transfer. However, the distinction between open- vs. closed- word class should be thoroughly considered before reaching such a conclusion.

4.7 Conclusions

The primary goal of this study was to address the noun-verb dissociation and identify the neural activity induced by the two word classes. We were interested in the temporal and spatial processing of the two grammatical classes and their differences. For that reason, we investigated the neural correlates of grammatical classes in a silent reading task by contrasting identical word forms that belong in different word classes. The differences yielded by the comparison of the global field power activity induced by noun and verb phrases demonstrated the two word classes activated partially overlapping neural networks in the early time window but were processed differently in the later stages of word processing. Indeed, differences were also identified at the early time window specific to the parietal sites related to verbal working memory. Specifically, both word classes activated the occipital, left temporal and parietal cortices during processing but only verbs induced activation at the left inferior frontal gyrus during the late time window. Bear in mind that these late spatial differences were not attributed to physical differences of the stimulus since word length, frequency and presentation time was matched between the two.

Our results should be measured up to comparable findings where the primary task is visual and the experimental component requires lexical processing induced by silent reading. Additionally, the spatiotemporal features of the MEG technique should be taken in consideration. As Pulvermüller, Shtyrova., & Ilmoniemib, (2003) argued, the

Minimum Norm Estimates technique – the source localization employed in our study- provides essentially an estimation of the sources brain areas, which is valid for all neuroimaging methods. The technique allows for inferences relevant to the general areas of the cortical lobes in combination with the temporal precision. With these considerations in mind, our findings are comparable with other studies that investigate the neural substrates of noun and verb processing. Limiting confounds such as the type of experimental task, the technology and methodology, it is expected that consistent and coherent evidence across varied studies should emerge.

The current study yielded findings that provide a satisfactory answer to the question posed in the introduction: the verbal and nominal processing is exemplified by distinct neural representations in accordance with the clinical reports. While earlier processing activated a partially similar network, the main differences were depicted in a later stage of processing: verbs were mainly processed at the left frontal cortex while nouns activated the left temporal lobe. We reason that this signified the processing of the lexical properties that differentiate the two grammatical classes.

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Appendix

STIMULI : VERB AND NOUN HOMOPHONES

IO	TU	IL/LO	I/GLI
abbraccio	abbracci	l'abbraccio	Gli... abbracci
addebito	addebiti	l'addebito	Gli... addebiti
anticipo	anticipi	l'anticipo	Gli... anticipi
arredo	arredi	l'arredo	Gli... arredi
bacio	baci	il bacio	baci
bagno	bagni	il bagno	bagni
ballo	balli	il ballo	balli
baro	bari	il baro	bari
blocco	blocchi	il blocco	blocchi
calcolo	calcoli	il calcolo	calcoli
cammino	cammini	il cammino	cammini
canto	canti	il canto	canti
castigo	castighi	il castigo	castighi
circolo	circoli	il circolo	circoli
compenso	compensi	il compenso	compensi
concilio	concili	il concilio	concili
conteggio	conteggi	il conteggio	conteggi
contrasto	contrasti	il contrasto	contrasti
covo	covi	il covo	covi
digiuno	digiuni	il digiuno	digiuni

disturbo	disturbi	il disturbo	disturbi
dono	doni	il dono	doni
filo	fili	il filo	fili
filtro	filtri	il filtro	filtri
fischio	fischi	il fischio	fischi
frammento	frammenti	il frammento	frammenti
freno	freni	il freno	freni
fumo	fumi	il fumo	fumi
grido	gridi	il grido	gridi
guadagno	guadagni	il guadagno	guadagni
incasso	incassi	l’incasso	Gli... incassi
invito	inviti	l’invito	Gli... inviti
Martello	martelli	Il martello	martelli
massaggio	massaggi	Il massaggio	massaggi
noleggio	noleggi	Il noleggio	noleggi
ostacolo	ostacoli	l’ostacolo	Gli... ostacoli
parcheggio	parcheggi	il parcheggio	parcheggi
presidio	presidi	il presidio	presidi
raduno	raduni	il raduno	raduni
reclamo	reclami	il reclamo	reclami
regalo	regali	il regalo	regali
regno	regni	il regno	regni

respire	respiri	il respiro	respiri
restauro	restauri	il restauro	restauri
rialzo	rialzi	il rialzo	rialzi
ricambio	ricambi	il ricambio	ricambi
ricavo	ricavi	il ricavo	ricavi
rifugio	rifugi	il rifugio	rifugi
rigetto	rigetti	il rigetto	rigetti
rilancio	rilanci	il rilancio	rilanci
rimbalzo	rimbalzi	il rimbalzo	rimbalzi
rinnovo	rinnovi	il rinnovo	rinnovi
risparmio	risparmi	risparmio	risparmi
risveglio	risvegli	il risveglio	risvegli
ritocco	ritocchi	il ritocco	ritocchi
rotolo	rotoli	il rotolo	rotoli
saccheggio	saccheggi	il saccheggio	saccheggi
salto	salti	il salto	salti
solco	solchi	il solco	solchi
sospiro	sospiri	il sospiro	sospiri
spaccio	spacci	lo spaccio	Gli... spacci
spreco	sprechi	lo spreco	Gli... sprechi
spunto	spunti	lo spunto	Gli... spunti
stimolo	stimoli	lo stimolo	Gli... stimoli
suono	suoni	il suono	suoni

taglio	tagli	il taglio	tagli