Grammar-Lexicon Distinction in a Neurocognitive Context

Integrating two theories

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GRAMMAR-LEXICON DISTINCTION IN A NEUROCOGNITIVE CONTEXT

Integrating two theories

PhD Thesis

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Resumé

Nye neuroimaging-teknikker og læsionsstudier bidrager til vores forståelse af, hvordan sprog understøttes neurokognitivt, mens psykolingvistiske studier tilbyder modeller af, hvordan og i hvilken rækkefølge forskellige sprogkomponenter processeres. De fleste af disse studier ser sprog enten fra et modulært eller fra et konnektionistisk perspektiv. Disse to tilgange har imidlertid begrænsninger. F.eks. er de ikke i stand til at give en samlet redegørelse for både agrammatisk afasi og posttraumatisk funktionel reorganisering.

En sprogbrugsbaseret teori om grammatisk kontra leksikalsk status (Boye & Harder, 2012) positionerer sig selv mellem generativ grammatik og konstruktionsgrammatik. En teori om reorganisering af elementære funktioner (REF-modellen; Mogensen, 2011; 2014) foreslår, at at neurokognitive funktioner er organiseret i tre lag, og tilbyder en redegørelse for posttraumatisk genopretning. Hensigten med den foreliggende afhandling er at udlede og teste hypoteser på basis af disse to teorier. De centrale forskningsfelter i afhandlingen er således grammatik-leksikon-forskellen og arbejdshukommelsen.

Afhandlingen betjener sig af fire forskellige metoder. 1) I et litteraturreview studeres forholdet mellem arbejdshukommelse og sprog i afasi. Studiet giver med basis i REF-modellen en redegørelse for ressourceoverlappet mellem de to funktioner. 2) I et korpus-studie undersøges en dissociation mellem grammatiske og leksikalske pronomener på i fransk agrammatisk tale. 3) I et adfærdseksperiment om flerordsproduktion undersøges forholdet mellem sprogproduktion og arbejdshukommelse ved hjælp af arbejdshukommelsesbelastning. 4) Samme flerordsproduktionsparadigme anvendes i en transkraniel magnetisk stimuleringsundersøgelse anvendes, hvor de forreste og bageste dele af den venstre nedre frontale gyrus moduleres gennem transkraniel magnetisk stimulering.

Resultaterne vidner om et potentiale for en succesfuld integrering af de to teorier. De giver desuden belæg for Boye & Harders (2012) teori om grammatik-leksikon-forskellen og for, at arbejdshukommelsen inddrages i sprogproduktion, som REF-modellen ville forudsige. Som et udgangspunkt for integrering af de to teorier udstikker den foreliggende afhandling retninger for fremtidig forskning i sprogets neurokognitive grundlag og dettes relation til arbejdshukommelse.

Abstract

Recent neuroimaging techniques and lesion studies contribute to our understanding of the neurocognitive underpinning of language in the brain, while psycholinguistic studies offer models of how and in which order different components are processed. Most of those studies see language either from a modular or from a connectionist perspective. These two approaches have limitations, however. For instance, they fail to provide a unified account of both agrammatic aphasia and functional reorganization following an injury. A usage-based theory of grammatical vs. lexical status (Boye & Harder, 2012) positions itself between Generative Grammar and Construction Grammar. A theory of the reorganization of elementary functions (REF-model; Mogensen, 2011; 2014) suggests a three-level organization of cognitive functions in the brain and accounts for post-injury recovery. The present thesis aims at deriving hypotheses and testing them based on these two theories. The grammar-lexicon distinction and working memory are thus central topics of this thesis.

This thesis employs four different methods. 1) A literature review investigates the relationship between working memory and language in aphasia. It provides an account in terms of the REF-model for shared resources between the two functions. 2) A corpus study explores a dissociation between grammatical and lexical pronouns in French speakers with agrammatism. 3) The relationship between working memory and language production is studied in a behavioural multi-word production experiment with working memory load. 4) The same multi-word production paradigm is also used in a transcranial magnetic stimulation study. In that study the anterior and posterior parts of the left inferior frontal gyrus are modulated through transcranial magnetic stimulation.

The results suggest a potential for a successful integration of the two theories. The findings further provide evidence for Boye & Harder's (2012) understanding of the grammar-lexicon distinction, and for the involvement of working memory in language production, as the REF-model would predict. As a starting point for integrating the two theories, the present thesis gives directions for future research on the neurocognitive underpinning of language and its relation to working memory.

The papers

The current thesis consists of four papers. I have written them in collaboration with researchers affiliated to research institutions in Denmark and abroad. My main supervisor Kasper Boye and co-supervisor Jesper Mogensen provided theoretical input and contributed to the structure and the design of the papers *Working memory and language impairment in aphasia: A causality dilemma* and *The meeting point: Where language production and working memory share resources*. Halima Sahraoui provided the data and methodological input for the paper *Grammatical and lexical pronoun dissociation in French speakers with agrammatic aphasia: A usage-based account and REF-based hypothesis*, while Peter Harder, Kasper Boye and Jesper Mogensen contributed to the theoretical framework, the structure, the design and the writing of the manuscript. The experiment behind *Grammar-lexical distinction in a TMS study* was carried out at the Danish Research Centre for Magnetic Resonance under Hartwig Siebner's supervision. Anke Karabanov provided input on practical issues related to the design, the results interpretation and the data analysis. Violaine Michel Lange designed the linguistic task, participated in the data acquisition and the analysis and contributed to the results interpretation and writing. Kasper Boye provided theoretical input to the linguistic task and contributed to the results interpretation. Hartwig Siebner and Gesa Hartwigsen were the main contributors of the TMS experimental design and they also contributed to the data analysis. I contributed to the design of all the studies, carried out the analyses, interpreted the results and wrote the papers. The present thesis consists of the following papers:

Ishkhanyan, B., Boye, K., Mogensen, J. (unsubmitted). Working memory and language impairment in aphasia: A causality dilemma.

Ishkhanyan, B., Sahraoui, H., Harder, P., Mogensen, J., & Boye, K. (2017). Grammatical and lexical pronoun dissociation in French speakers with agrammatic aphasia: A usage-based account and REF-based hypothesis. *Journal of Neurolinguistics*, *44*, 1-16.

Ishkhanyan, B., Boye, K., Mogensen, J. (unsubmitted). The meeting point: Where language production and working memory share resources.

Ishkhanyan, B., Michel Lange, V., Boye, K., Karabanov, A., Hartwigsen, G. & Siebner, H. R. (unsubmitted). Grammar-lexicon distinction in a TMS study.

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CHAPTER 1

General introduction

1.1 Introduction

Recent neuropsychological and neuroscientific studies have contributed significantly to our understanding of language. For instance, using modern neuroimaging techniques, researchers have mapped different components of language in the brain, expanding beyond the classical Wernicke's and Broca's areas (e.g. Price, 2010; 2012, Friederici, 2012). Additionally, psycholinguists came up with various models that reflect how and when different components of language, such as phonology or lexicon, are processed (Bock & Levelt, 2002; Indefrey & Levelt, 2004; Dell, 1986). Brain lesion studies allowed researchers to investigate the organization of language in the brain through exploring the linguistic symptoms that occur as a result of a brain injury, and the strategies injured individuals use to adapt to the deficit (Henseler, Regenbrecht & Obrig, 2014; Kolk, 1995). Finally, language has been looked at in connection with other cognitive functions, such as attention and working memory (WM) (Gathercole & Baddeley, 2014; Baldwin, Moore & Dunham, 1995).

Most of psycho- and neurolinguistic studies see language either from a modular or from a connectionist perspective. Modularity suggests that the cognitive system consists of domain-specific, autonomous and non-interactive modules that are anatomically localized and specialized for one cognitive function (Fodor, 1983), one such module being language or a component of language (Pinker, 1999). Connectionists, on the contrary, argue that the cognitive system is an interactive and domain-general network (Bechtel & Abramsen, 1991). Serial processing models of language production would be examples of modular approaches (Bock & Levelt, 2002), while parallel processing models are associated with connectivity (Dell, 1986).

The dichotomy between modular and connectionist approaches is mirrored in brain injury studies. For instance, the representation accounts of agrammatism argue that certain representations of language (e.g. tense) are irreversibly lost (as in the Tree Pruning Hypothesis, Friedmann & Grodsinsky, 1997). If this was true, individuals with agrammatism would never be able to process the lost function (e.g. past tense in this case). However, it has been shown that despite the deficit, individuals with agrammatism are still able to produce certain structures with some difficulties, which would not be possible, if the representation was lost (Sahraoui & Nespoulous, 2012; Kolk & Heeschen, 1992; Kolk, 1995). Thus, the modular approach to agrammatism has its limitations and does not account for variation within and between individuals. Processing accounts, on the contrary, suggest that no language components are lost to injury, and that agrammatism is caused by a slowing down of processing or by resource reduction (Kolk, 1995; Caplan, 2012). An extreme connectionist view suggests that agrammatic symptoms are not unique to lesion localization and can accompany any type of aphasia and that grammatical items are affected because of impaired lexical access (Dick, Bates, Wulfeck, Utman, Dronkers & Gernsbacher, 2001; Blackwell & Bates, 1995). While there is evidence that agrammatism is not limited to Broca's area, it still accompanies lesions with a certain location (Mazzocchi & Vignolo, 1979; Bastiaanse & Thompson, 2012). Therefore, extreme connectionist views do not account for agrammatism either.

Modular or connectionist views also do not account for functional localization and reorganization in the brain following an injury (Mogensen, Boye, Siebner & Harder, in progress). Kolk's adaptation theory (1995) is the only processing theory that accounts for variability and adaptation strategies in individuals with agrammatism. The theory, however, lacks linguistic (why grammatical but not lexical items are omitted to adapt to the deficit) and neurocognitive (why certain individuals are better at adapting to the deficit than others) explanations. It is thus necessary to come up with a theory that would account for language deficits and functional recovery following a brain injury.

In this thesis I explore two theories that position themselves between modularity and connectionism, the integration of which account for language processing both in healthy and injured brain. The first one is a usage-based linguistic theory and focuses on the difference between grammar and lexicon (Boye & Harder, 2012). The reorganization of elementary functions (REF) model is a neurocognitive model and it accounts for recovery patterns and variability among individuals with brain injury (Mogensen, 2011; 2014). The two theories will be presented and discussed in detail in Sections 1.2 and 1.3 respectively.

In addition to language, I also explore what role WM plays in language processing. WM is generally defined as a temporary storage for maintaining and manipulating limited amount of information (Baddeley, 2003a). I am choosing WM as another cognitive function to explore because a conversation about modularity and connectionism would not be complete without an additional cognitive function. Modular theories claim that language is independent from other cognitive functions, while connectionists suggest a constant interaction. Thus, it would be interesting to explore the relationship of language and one other cognitive function that has been shown to have an interaction with language processing. WM is such a cognitive function (Acheson & MacDonald, 2009; Baddeley, 2003a; Baddeley & Hitch, 1974; Daneman & Merikle, 1996). Moreover, Kolk (1995) has described agrammatism in terms of WM capacity limitations. However, he did not account for why grammatical items are more vulnerable to deficit than lexical items. Boye & Harder's (2012) theory provides such an account.

In this thesis I will put together the two above-mentioned theories and WM to explore how grammar and lexicon are processed both in non-injured and aphasic populations, and what role WM plays in this processing. The thesis consists of six chapters. Chapter 1 is an introduction to the relevant research areas and the aim and methodologies of this thesis. Here I introduce the two theories, the research questions and the methodology used to carry out the studies. Chapters 2 to 5 are independent research papers. Chapter 2 explores WM and language deficits in brain injured population and provides a REF-model account for it. Chapter 3 is a corpus study of French agrammatic speakers. Chapter 4 is a behavioural experiment, exploring the relationship between language production and WM. Chapter 5 is a transcranial magnetic stimulation (TMS) experiment. Chapter 6 comprises general conclusions.

1.2 A usage-based account on grammatical status

Like neurocognitive models, linguistic theories about grammar also position themselves at one of the two extremes equivalent to modularity and connectionism. Chomskyan Generative Grammar is the modular extreme for linguistic theories (e.g. Chomsky, 1965; 1975). According to Generative Grammar, grammar is an independent module and consists of rules that generate complex sentences, while lexicon is a set of items, on which those rules can be applied.

Construction Grammar is the other extreme of linguistic theories and suggests that grammar and lexicon are a set of stored items and thus they are not different from each other (Hoffmann & Trousdale, 2013). In the recent years both of the extreme positions have undergone certain modifications, which resulted in some mutual rapprochement between the two poles. Pulvermüller, Capelle & Shtyrov (2013) suggested reconciliation between the two extremes. They agree with the Construction Grammar theory that language is part of the larger cognitive system and that grammar and lexicon are interwoven but they also present neurophysiological evidence supporting the distinction. The polarization continues to exist, however, as witnessed by recent attacks on the Chomskyan position (Dabrowska, 2015; Ibbotson & Tomasello, 2016).

The limitations of these theories can be seen when examining linguistic deficits in injured population, specifically symptoms occurring in agrammatic aphasia. Individuals with agrammatic aphasia tend to omit or substitute grammatical items (Goodglass, 1996). If grammar was modular, in agrammatism a total absence of grammar would be observed. However, extensive research shows that despite the difficulties of producing or comprehending grammatically complex sentences, individuals with agrammatism are still able to process grammar to some extent and their performance may vary from task to task (Kolk, 1995; Hofstede & Kolk, 1994; Sahraoui & Nespoulous, 2012). If Construction Grammar was true in its strongest version, in agrammatism one would not expect to see strong preference for omitting or substituting grammatical items but rather grammatical and lexical items would be equally affected.

The usage-based theory of grammatical status (Boye & Harder, 2012) positions itself between Generative and Construction Grammar. In line with Generative Grammar but in contrast to Construction Grammar, it maintains a categorical distinction between grammar and lexicon. In line with Construction Grammar and in contrast to Generative Grammar, on the other hand, it sees grammar as a set of function-based linguistic conventions. According to the theory, the grammar-lexicon contrast serves to prioritize complex linguistic messages. Linguistic items that are potentially discursively primary are lexical, while discursively secondary items are defined grammatical. In other words, grammatical items cannot convey the main point of an utterance. In example (1) the lexical items are in bold.

(1) The **boy** is **eat**ing an **apple**.

Let's omit first the grammatical items (2) and then the lexical (3) ones to see what we are left with.

(2) boy eat apple

(3) the is ing an

As can be seen in (2), the utterance, despite not being grammatical, is still carrying a meaning. We may not know the tense of the verb and the number of apples but we have the information about a boy eating an apple. (3), however, consisting of only grammatical items, is totally meaningless. Moreover, (2) is an utterance that can be produced by an agrammatic speaker but there is no known language disorder, where the individual produces utterances like (3).

If placed in the context of processing theories of agrammatism, the Boye & Harder (2012) theory would explain why grammar is more vulnerable to deficit. For instance, according to Kolk (1995), agrammatism is a result of a slowing down of processing and fast decay. Due to temporal constraints, agrammatic speakers often rely on ellipsis to produce meaningful utterances. Healthy speakers to a lesser extent also use ellipsis in their speech. Kolk (1995), however, does not provide an explanation to why grammatical and not lexical items are omitted due to a slowing down of processing. The Boye & Harder (2012) theory suggests that this happens because grammar is secondary and it can be omitted to preserve the meaning of the utterance, if there are processing constraints. Thus, the theory opens for two possible accounts of agrammatism: 1) Prioritization (the less important grammatical items can be dispensed with), 2) Dependency (as secondary elements grammatical items are dependent on lexical hosts). More about the theory and agrammatism can be found in Section 1.5 and Chapter 3.

1.3 The REF-model and post-injury language recovery

As mentioned above, the REF-model (Mogensen 2011; 2014) positions itself between the two extremes of modularity and connectionism. The REF-model accounts not only for functional organization in the healthy brain but also recovery following a brain injury. In the context of language processing the REF-model provides an account for functional organization of the language and recovery in individuals with aphasia.

The REF-model assumes that cognitive functions are organized in three levels: elementary functions, algorithmic strategies and surface phenomena (Figure 1.1). Out of these four only the bottom ones – elementary functions (EFs) are truly localized and highly modular but they do not represent cognitive functions in a traditional sense. EFs can be described using mathematical terms and they contribute to rather basic information processing. Most EFs therefore simultaneously contribute to more than one traditionally defined cognitive function. Cortical areas consist of numerous interacting EFs (e.g. inferior frontal gyrus or middle temporal gyrus). As EFs are strictly localized, they can be lost to injury and cannot be recreated elsewhere in the brain.

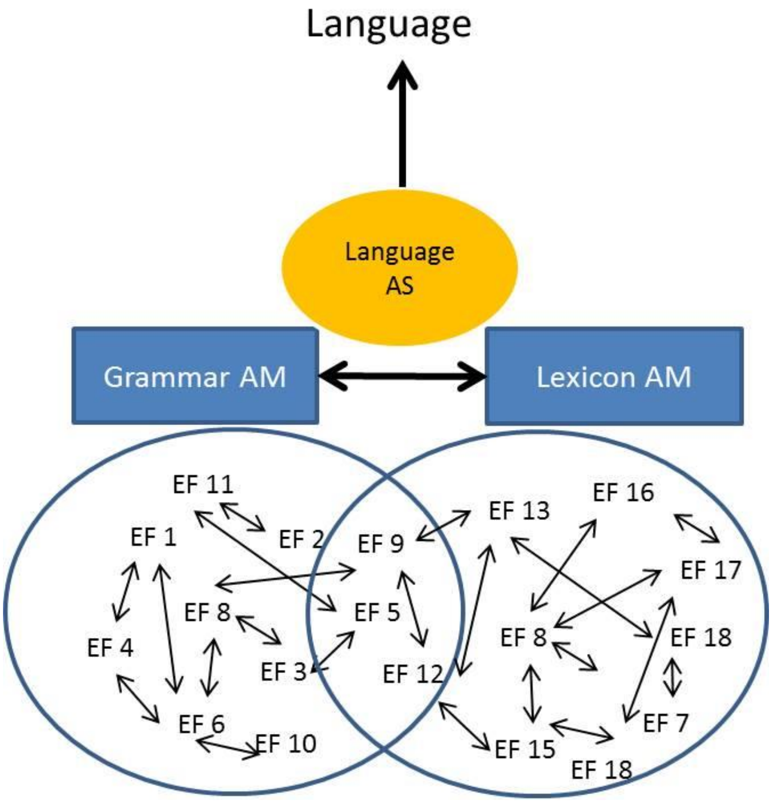

Figure 1.1 Simplified presentation of the REF-model. Elementary functions (EFs) interact to create the grammar and lexicon algorithmic modules (AM), which in turn result in the language algorithmic strategy (AS). The language AS programs the surface phenomenon of language.

The top level of the REF-model comprises surface phenomena. Those can be observed at a behavioural level and measured experimentally. When a brain injury occurs, the lost function and the subsequent recovery are manifested at this level.

The mid-level of the model consists of algorithmic strategies (ASs) that bridge the gap between EFs and surface phenomena. ASs are created through learning and experience and they are a result of interacting EFs. ASs consist of the neural substrate of the EFs and the connections between them. Thus, unlike the strictly localized EFs, ASs are distributed throughout the brain. ASs serve as a program or a base for surface phenomena. For example, if the surface phenomenon is language production, first a language production AS must be created to program the surface manifestation of language.

Apart from ASs, the interaction of EFs can also create algorithmic modules (AMs). Unlike ASs, AMs cannot support surface phenomena on their own. Therefore, it is necessary that they also interact to create additional ASs, which in turn can manifest into a surface phenomenon. In this context, and in line with Boye & Harder’s (2012) theory, grammar is thought to be such an AM. It requires lexicon to be manifested in, for example, language production. Grammar on its own cannot result in meaningful utterances. Therefore, it has to interact with the lexicon AM to create a language production AS, which in turn can be observed as a meaningful utterance at a surface level.

There are three stages of post-injury language recovery that can be assessed and described at behavioural level (Kiran, 2012; Marsh & Hillis, 2006). In the acute stage, which corresponds to the first two weeks following the injury, severe language deficits, such as word finding difficulties or impaired comprehension can be observed. At this stage, the activation of language areas in the brain is at the minimum (Saur, Lange, Baumgaertner, Schraknepper, Willmes, Rijntjes & Weiller, 2006). From the REF-model perspective, the neural substrate (i.e. the EFs) underlying the ASs of some surface phenomena are irreversibly lost (Mogensen, 2014). Consequently, the ASs are lost and the surface phenomena are manifested as severe deficits, and little activation in the corresponding brain areas when performing a language task is observed. Certain individuals may manifest acute recovery due to reperfusion (Marsh & Hillis, 2006).

In the sub-acute stage (the first few months post-onset), language recovers rapidly due to neural reorganization (Marsh & Hillis, 2006). Brain activation increases and involves the ipsilateral hemisphere (Saur et el., 2006). This is when the first results of the reorganization of elementary functions may be observed. Through backpropagation a group of EFs, which previously were not involved in the organization of language ASs, interact and create new ASs (Mogensen, 2014). If the behavioural outcome of the new AS is functionally inadequate, the process repeats with a slight change in the organization of the new AS, until the behavioural outcome is successful.

The chronic stage begins a couple of months post-onset and continues for the rest of the individual's life. The recovery continues in this period through therapy, experience and learning (Kiran, 2012). It may not be as rapid as in the previous stage but individuals with aphasia continue improving their language skills and the brain activation returns to the left hemisphere (Marsh & Hillis, 2006; Saur et al., 2006). The REF-model suggests that at this stage the majority of the individuals with aphasia develop a number of successful ASs, which result in recovered surface phenomena that are not as perfect as before the injury but nevertheless are better than the manifestations of the acute phase. Generally, post-injury development of ASs depends on the amount of lost EFs, pre-traumatic connections between EFs and the post-injury experience of the individual, which includes but is not limited to therapy.

More about the REF-model and its role in healthy and injured brain can be found in Chapters 2, 3 and 4.

1.4 Language production and working memory models

Language production models account for the processes involved from the moment of the formulation of the idea in the brain until articulation (Garrett, 1975). All of those models, whether they account for a single word or multi-word utterance production, have at least three levels in common: semantic (conceptual, message), lexical (lemma) and phonological. The differences between the models lie in the extra levels required for, for example, grammatical encoding in multi-word utterance production models, serial and parallel processing and the methods used for developing those models, which will be described below.

One of the characteristics of modularity is double dissociation (two modules functioning independently of each other). This can be shown with two functions (A and B) measured in two individuals (X and Y) with brain lesions. Individual X shows signs of function A impairment, while function B is preserved. Individual Y, on the contrary, is impaired in function B with function A preserved. Double dissociation studies led to constructing the highly modular single word processing model (Ellis & Young, 1988; Howard & Franklin, 1988), which assumes that there is a single semantic system for both written and spoken language and both production and comprehension, while there are separate lexicons for each of the four domains (reading, writing, oral language comprehension and production). The model also assumes four separate temporary buffers for holding input and output phonemes and graphemes. Interestingly, the single word processing model is the only one that includes some kind of a temporary storage.

The connectionist version of the single word production model was developed by Dell (1986). This model also comprises the same three levels (semantic, lexical and phonological) but it claims that all linguistic items represent interconnected nodes and the nodes interact both within and between levels. When planning a word production, all the nodes are activated and the ones with the highest activation are selected. Neuroimaging and electroencephalography (EEG) evidence provided more information about language production planning. Through a meta-analysis Indefrey & Levelt (2004) developed a model that not only accounts for the order and the time course of the events for one-word production but also for which brain areas are involved in those events.

Speech error studies led to developing language production models, which account for multi-word production (Fromkin, 1971; Garrett, 1975; Bock & Levelt, 1994). The earliest modular model comprises six distinct levels (Fromkin, 1971). The top level is the meaning level. This level is conceptual and does not have linguistic features. Once the intended meaning is formulated, the syntactic-semantic features of the utterance are selected, followed by intonation and primary stress selection. The next step is the selection of appropriate lexical and grammatical items from the lexicon and thus syllables are specified. The utterance further undergoes morphophonemic modifications, which leads to strings of phonetic segments. Finally, phonetic/phonological rules are applied to prepare the utterance for articulation.

Garrett (1975) observed that speech errors can be either at word level or at phoneme level. She thus suggested separate grammatical and positional (phonological) levels of language planning. Garrett’s model (1975; 1980) consists of three levels: semantic, sentence and motor. It is at the sentence level where lexical words are selected independent from grammatical items. At a later stage grammatical items are added, which is followed by the positional stage, where the correct word order is selected (Garrett, 1980).

The Bock & Levelt (1994) model is a more complex version of Garrett’s (1975) model with an element of parallel processing, though still basically a serial processing model. In the Bock & Levelt (1994) model at the functional level first the lemmas are selected (words with their grammatical but not phonological properties) and their role in an utterance is assigned to them. At the positional level, like in Garrett’s (1975) model, the order of the words in the sentence is decided, which is followed by the phonological encoding level. The whole model is controlled by the self-monitoring component that allows going back and correcting potential errors. Bock & Levelt (2002) assume incremental processing, which means that each element of the utterance is built up based on the order, in which they appear in speech. A new element can start being processed at a higher level (e.g. the message level) of the model, once the previous element has moved to a lower level (e.g. the phonological level).

Dell & O'Seaghdha (1992) developed a multi-word utterance production model, which reconciles connectionist and modular models. While they propose the same three discrete levels of production, they also argue for lemma and phonological sublevels in the lexical access level. According to Dell & O'Seaghdha (1992), those sublevels despite being distinct, like in modular models, still interact with each other, like in connectionist models.

The Boye & Harder (2012) theory fits with those psycholinguistic models of language production that suggest lexical items are planned prior to and independent from grammatical items (Garrett, 1975; 1980) and assume incremental processing (Bock & Levelt, 1994; 2002). As according to the theory grammatical items are background, less important and dependent on lexical items, lexical items should be planned first, after which the grammatical items can start being planned at higher levels of the model. The REF-model also has a common ground with language production models. The individual stages of language production can correspond to individual AMs, and the full production model can correspond to an individual AS, which results in a surface phenomenon (a multi-word utterance in this case).

Independently of language production models WM models have also been developed. One early WM model, which is still widely accepted, comprises two domain-specific elements: a phonological loop (for processing auditory verbal information) and a visuospatial sketchpad (for processing non-verbal visual information) (Baddeley & Hitch, 1974). This model has additionally a domain-general attentional component called central executive. Later an episodic buffer was added to the model as a temporary storage for information retrieved from long-term memory to connect with the phonological store and the visuospatial sketchpad (Baddeley, 2000). However, the episodic buffer has not yet been studied thoroughly (Baddeley, 2003b). Another important later change resulted in seeing the phonological loop as consisting of two components. One of them is the phonological store, where purely phonological information is stored. The second component is the articulatory rehearsal, which is responsible for sub-vocal rehearsal to keep the phonological information active at the phonological store (Baddeley, 2003b).

A domain-general model suggested by Cowan (1988) links WM, short-term memory (STM) and long-term memory together. In his model Cowan does not separate the phonological loop and the visuospatial sketchpad. He rather suggests that the two are different aspects of activated memory and are subject to interference. Additionally, all types of memories are seen as having limited duration and capacity (Cowan, 2008), and it has been suggested that limitations become more apparent when brain injury occurs (Kolk, 1995; Miyake, Carpenter & Just, 1994).

Despite the obvious similarities between WM and language production models, such as a phonological component that may be shared between the two systems, not many attempts have been made to link the two together. Acheson & MacDonald (2009) have made such an attempt, by arguing that the serial ordering in language production requires WM involvement. With possibly shared neural substrate (EFs) and AMs the REF-model (Mogensen, 2014) may provide additional account for the interaction of WM and language production (see Chapter 5 for details).

1.5 Aphasia and agrammatism

Aphasia is an acquired language disorder that occurs as a result of severe brain injury (Damasio, 1992). Double dissociations have been observed across aphasia types. For instance, Wernicke’s aphasia has associated with fluent speech, impaired comprehension, preserved grammar and lexical deficits, whereas individuals with Broca’s aphasia are described as typically having non-fluent speech, preserved comprehension, omission of grammatical items (agrammatism) and impaired lexicon (Ingram, 2007). However, substantial research has shown that these dissociations are not as clear-cut. Individuals with Wernicke’s aphasia, for instance, have grammatical deficits in their production in the form of paragrammatism, which is characterized by substitutions of bound grammatical morphemes (Butterworth & Howard, 1987), while individuals with Broca’s aphasia have been shown to have difficulties understanding syntactically complex sentences (Caramazza & Zurif, 1976) and retrieving lexical items (e.g. Kohn & Goodglass, 1985). As for WM deficits, they are present in both aphasia types but individuals with Wernicke’s aphasia are more affected (Baldo, Katseff, & Dronkers, 2012; Gordon, 1983; Kasselimis, Simos, Economou, Peppas, Evdokimidis & Potagas, 2013). Such evidence suggests no clear-cut differences between aphasia types. In fact, Kolk & Heeschen (1992) argue that agrammatism and paragrammatism are different manifestations of the same deficit. They suggest that agrammatic production is a result of adaptation to the deficit. Individuals with aphasia have a slowing down of processing and thus they omit grammatical items, relying on ellipsis to produce the intended utterances. In paragrammatic production, on the contrary, there is no strategic adaptation, which results in the production of incomplete and grammatically erroneous sentences (Kolk & Heeschen, 1992; Kolk, 1995).

Agrammatism and paragrammatism are interesting language deficits from the Boye & Harder (2012) perspective, as they are both characterized by impaired production of grammar. The Boye & Harder (2012) theory thus can contribute to agrammatism research by defining what grammar is. In fact, it complements Kolk's (1995) theory by providing an account for why grammatical and not lexical items are omitted to adapt to the deficit. Agrammatism and paragrammatism are also interesting from the REF-model (Mogensen, 2014) perspective, as those symptoms are not only a result of a severe brain injury but also the strategies individuals are using to adapt to the deficit (Kolk & Heeschen, 1992). On top of that, as Kolk's (1995) theory of agrammatism suggests a slowing down of processing, it is reasonable to discuss the role of WM in this context.

There are, however, numerous theories that attempt to account for symptoms associated with agrammatism. Traditionally, they are divided into representation and processing theories (Bastiaanse & Thompson, 2012). The representation theories (e.g. the Tree Pruning Hypothesis; Friedmann & Grodzinsky, 1997) claim that a certain linguistic representation is permanently lost from the brain as a result of an injury and cannot be replaced, while processing theories suggest that the lesion causes certain abnormalities in language processing rather than representation (e.g. Resource Reduction Accounts; Caplan, 2012). There are several processing theories based on empirical data that account for the manifestations of agrammatic language production. Below I will discuss the ones that I think can be related to WM limitations.

A central theory accounting for both agrammatic production and comprehension is suggested by Kolk (1995). As mentioned above, he argues that agrammatic symptoms are a result of a slowing down of syntactic processing. This can happen either because of slow activation or fast decay in temporary storages. Kolk's theory is supported by the findings of Miyake et al. (1994), who observed comprehension deficits in healthy individuals when sentences are produced faster than normal. Kolk (1995) observed that omissions similar to those found in agrammatic patients occur in normal speech, too, although with a lower frequency. He thus suggests that the linguistic patterns observed in agrammatism are not mere deficits but rather the result of the injured individual's adaptive behavior to the processing limitations.

The idea of adaptive behavior was supported by a picture description study, examining syntactic priming effects in a group of individuals with Broca's aphasia (Hartsuiker & Kolk, 1998). The authors hypothesized that priming would facilitate production in individuals with Broca's aphasia because it reduces the required processing load. Indeed, a priming effect was observed in individuals with Broca's aphasia. Similar effects were observed in non-injured individuals as well but only in the session when they were aware of the aim of the study. The authors concluded that while non-injured participants used priming as a strategy, for individuals with aphasia it was an unconscious process to facilitate the production of syntactically complex sentences and to compensate resource limitations in speech production.

The general symptoms of agrammatism, such as the omission of grammatical morphemes, also received a processing load explanation. In a sentence production study Caplan & Hanna (1998) showed that indeed individuals with aphasia tend to omit function words. They attributed these symptoms to processing limitations. According to the authors, grammatical words require more processing load. That is why they are omitted. It remains unclear, though, what "more processing load" means more precisely, and why grammatical words would require more load.

Another processing theory accounts for the problem of anaphoric pronouns in agrammatism (Avrutin, 2006). It has been shown that individuals with agrammatism often omit or substitute pronouns. Avrutin (2006) suggested that this is because individuals with agrammatism are not able to establish the appropriate links between pronouns and their antecedents. In other words, their syntax is "weak" and they have access to only "narrow syntax" (i.e. access to the information of the current utterance), while the connection between the pronoun and its antecedent is lost. This happens as a result of a slowing down of processing. Therefore, it can be argued that the processing component of WM becomes limited and it is only able to handle information that is within the "narrow syntax."

Avrutin's (2006) suggestion was extended to time reference problems in aphasia, introducing the Past Discourse Linking Hypothesis (PADILIH) (Bastiaanse, Bamyaci, Hsu, Lee, Duman & Thompson, 2011). According to Bastiaanse and colleagues (2011), individuals with agrammatism are better at processing verbs that refer to future and present because those verbs do not require discourse linking, while reference to the past is discourse linked and therefore more difficult to process. In other words, individuals with agrammatism can easily access what is "here and now," while when they need to refer to the past, they have to access to information that is not readily present and therefore it requires additional processing load. This theory has been further supported by empirical findings in various languages (Bastiaanse, 2013). Reference to the past was clearly impaired in English, Dutch, Turkish and English-Swahili bilingual speakers. I would argue that this may also be a result of WM limitations. Referring to the past may require an additional processing load, which may not be available to individuals with agrammatism. Further experiments could possibly show the relationship between specific grammatical deficits in agrammatic production and WM limitations.

The lexical and grammatical divide has been long discussed in agrammatism. While for certain grammatical items their grammatical nature and thus impairment in agrammatic production is clear-cut (e.g. past tense suffixes), some items, such as prepositions and pronouns are in a gray zone and require further classification (Froud, 2001; Druks, 2016). In fact, in several studies it has been shown that those prepositions, which are defined as grammatical (syntactic or functional), are more prone to impairment, than those that are defined as lexical (Friederici, 1982; Froud, 2001). Boye & Harder's (2012) theory suggests a solution to this problem, providing tests for classifying disputable items into grammatical and lexical. One such test for pronouns can be found in Chapter 3.

1.6 Aims and research questions

The current project has three main aims. As a starting point, I would like to integrate the Boye & Harder (2012) theory and the REF-model (Mogensen, 2011; 2014) - a linguistic theory and a neurocognitive model that place themselves between the modular and connectionist extremes of neurocognitive research. Two of the papers in this thesis (Chapter 3 and 4) address this integration, while the other two (Chapter 2 and 5) address one or the other.

The second aim is to derive and test predictions about processing differences between grammar and lexicon based on the Boye & Harder (2012) theory. Lexical items are potential bearers of the primary point of a message. Grammar, being discursively secondary, should be planned and processed dependent on lexicon. Therefore, it may require more processing load than lexicon. Due to its secondary status grammar is more easily dispensed with when brain injury occurs or when processing load is added. In this project I am using various methods, such as corpus study and transcranial magnetic stimulation (TMS) in both healthy and brain injured population to determine the processing patterns of grammar and lexicon.

The third aim is to explore the relationship between WM and language both in healthy and injured populations through deriving and testing predictions based on the two theories. Both of the above-mentioned theories can make predictions about WM in relation to language processing. The Boye & Harder (2012) theory suggests that grammar and lexicon have different processing requirements. Therefore, grammatical and lexical items may use WM storage differently. The REF-model suggests a close interaction between WM and language. According to the REF-model, WM and language may have shared EFs and AMs. As a result, when shared EFs of WM and language are lost to injury, aphasia is accompanied by WM deficits. My focus is on language production in particular because while there is an extensive research about WM and language comprehension, there is still a lack of knowledge about what role WM plays in language production. The first paper (Chapter 2), however, has more focus on comprehension due to lack of aphasia and WM deficit research on production.

Finally, I am investigating how individual variability affects language processing and how individuals with agrammatism adapt to the deficit from the REF-model perspective. My general research questions derived from the above-mentioned aims are the following:

1. Are homophonous grammatical and lexical items planned and processed differently?

2. Are distinct cortical areas involved in the processing of homophonous grammatical and lexical words?

The processing differences of lexical and grammatical words have been studied previously (Gordon & Caramazza, 1982; Münte, Wieringa, Weyerts, Szentkuti, Matzke & Johannes, 2001; Bell, Brenier, Gregory, Girand, & Jurafsky, 2009; Segalowitz & Lane, 2000). In those studies, however, the grammar-lexicon distinction is intuitive and theoretically naïve. The Boye & Harder (2012) theory provides a definition of what grammatical and lexical items are and further raises the question of processing differences of grammatical and lexical items that would be homophonous. For instance, the Danish indefinite article *en* and *et* would be classified as grammatical, while almost homophonous numerals *en* and *et* ('one') would be classified as lexical according to Boye & Harder (2012). In Chapters 4 and 5, experiments targeting these elements will be described.

3. Is there a dissociation between linguistic items defined as grammatical and lexical by Boye & Harder (2012) in agrammatic speech?

Pronouns and prepositions, which are traditionally defined as grammatical items, have been shown to have dissociated impairment in agrammatism. In Romance languages pronouns classified as strong or non-clitic are more preserved in agrammatism, while those that are classified as clitic pronouns, are more impaired (Lonzi & Luzzatti, 1993; Stavrakaki

& Kouvava, 2003; Chinellato, 2004, 2006; Rossi, 2007). In addition to that, as described above, lexical prepositions are more impaired in agrammatism than grammatical ones (Friederici, 1982). The Boye & Harder (2012) theory provides a new classification of linguistic items, which allows to further explore the dissociation of those items. In Chapter 3 we answer this question through a corpus study of French agrammatic speech.

4. Do language and WM share resources? If so, what kind of resources do they share?

5. Is there a causal relationship between linguistic and WM deficits in aphasia?

Extreme modularist approaches would claim that language and WM do not share resources, while extreme connectionists would suggest that everything is shared. There is evidence that language and WM impairment accompany each other in brain injury (Goodglass, Gleason & Hyde, 1970; Gordon, 1983; Heilman, Scholes & Watson, 1976; Murray, 2012). However, it is still unclear whether linguistic deficits cause WM limitations or WM limitations cause linguistic deficits. The REF-model suggests the possibility of a shared neural substrate. The relationship between WM and language is further explored in Chapters 2 and 4.

6. To what extent are the symptoms of agrammatism a result of an injury and to what extent a result of reorganization?

The REF-model suggests that the behaviour observed at a surface level is a result of reorganization of remaining EFs following the injury. It is thus possible that each individual with agrammatism will develop his or her own unique adaptive strategy to cope with the deficit. Such strategies will be discussed in Chapter 3.

Specific hypotheses will be presented in the relevant chapters.

1.7 Methodology

In order to answer the research questions, we used various methods to carry out our studies. Each of the four methods implemented in this thesis is represented in one of four articles that constitute the backbone of the thesis. Three out of the four studies are lesion studies one way or the other.

In the pre-functional neuroimaging era lesion studies were the gold standard for mapping cognition in the brain. In fact, such studies can be dated back to Broca (1861) and Wernicke (1874), who discovered the primary language areas in the brain through studying the behavioural deficits in patients and connecting it to a corresponding lesion revealed in autopsy. Lesion studies became the main method Luria (1947; 1973) used in post-World War II era, when a large number of otherwise healthy individuals with focal brain injury and various behavioural symptoms sought neurological help. Brain lesions and accompanying behavioural symptoms have also contributed to building neurocognitive models (e.g. Ellis & Young, 1988). On top of that, the investigation of the deficit patterns in individuals with brain lesions in the language areas contribute to testing various linguistic theories. Such studies date back to Goodglass & Hunt (1958), where they test Chomsky's (1957) theory of syntax. The Boye & Harder (2012) theory and the REF-model (Mogensen, 2014) are two other theories that can be tested using data of injured population with aphasia.

The first paper (Chapter 2) is a theoretical paper, where we reviewed literature related to WM and aphasia to detect the relationship between language and WM deficits. We summarized the results and integrated the various findings with the REF-model, providing a new neurocognitive model that accounts for linguistic and WM deficits in aphasia, which can also be generalized on other cognitive functions. At first we wanted to keep our focus on agrammatic production. However, the majority of the relevant studies explore the relationship between WM and sentence comprehension deficits, which may accompany other aphasic syndromes, too (Caplan, Hildebrandt & Makris, 1996). Thus, we examined all the studies that explored the relationship between WM and a language measurement.

The second paper is a corpus study on French corpora of agrammatic individuals and their non-injured controls (Chapter 3). Spontaneous speech corpus analysis is a widely accepted method of quantitative research in injured population (Martínez-Ferreiro, González, Clari & Bastiaanse, 2017; Prins & Bastiaanse, 2004; Saffran & Berndt, 1989; Rochon, Saffran, Berndt & Schwartz, 2000). Unlike controlled experiments, spontaneous speech corpora allow an in-depth analysis of the language production of the individual with aphasia. Moreover, it is closer to natural speech production and thus provides more accurate information about the linguistic deficits and language recovery (Prins & Bastiaanse, 2004). Spontaneous speech analysis has its disadvantages, too. It is more difficult to test linguistic hypotheses using speech corpora because normally aphasic speech samples are not large enough to investigate structures that do not occur frequently enough, while in controlled experiments it is possible to elicit the structures in question. However, for testing the predictions of the Boye & Harder (2012) theory and the REF-model (Mogensen, 2014), an agrammatic speech corpus study is a good starting point.

The third paper (Chapter 4) is a language production and WM interaction behavioural experiment. As language production and WM studies are not common in general (Acheson & MacDonald, 2009) and they have not been previously tested in injured population, we decided to carry it out in healthy individuals first. Satisfactory results would allow us to extend the experiment and create an aphasia-friendly version of it.

In the fourth study (Chapter 5), we used transcranial magnetic stimulation (TMS) to modulate the anterior and the posterior parts of the left inferior frontal gyrus (LIFG). The former is known for processing semantic information, while the latter is known to be involved in syntactic processing (Price, 2010). TMS is a safe method for creating so-called virtual lesions to investigate the casual relationship between a brain region and a task (Devlin & Watkins, 2008). Through TMS it is possible to create transient noise into the neural substrate that is in the process of performing a task, which leads to longer RTs (Pascual-Leone, Bartres-Faz & Keenan, 1999). In comparison to lesion studies, it has the advantage that the virtual lesion is highly localized and thus a limited part of the cortex is being modulated in the process for a short period of time. Therefore, it is possible to observe the deficits unique to a lesion in a specific part of the brain that has not undergone the process of reorganization and recovery yet. However, the latter also becomes a disadvantage. Since the virtual lesion lasts for such a short period of time, reorganization in the brain does not occur and thus it is not possible to study linguistic patterns that are unique to recovery and not the lesion. While TMS has been widely used in language studies, the focus has always been on one-word production or sentence comprehension. This study is unique because for the first time it is investigating the effects of TMS on three-word production.

CHAPTER 2

Working memory and language impairment in aphasia: A causality dilemma

2.1 Introduction

Working memory (WM) is defined as a temporary storage for processing a limited amount of information, which directly interacts with attention and long-term memory (Baddeley, 2007). Both the existing literature on WM and the literature on language processing (whether injured or non-injured processing) indicate a relationship between WM and language (Acheson & MacDonald, 2009; Baddeley, 2003a; Baddeley & Hitch, 1974). From the perspective of the WM literature, such a relationship follows from the claim that verbal cues facilitate the storage of non-linguistic information in WM (Conrad & Hull, 1964). Accordingly, language plays an important role in existing theories of WM (Baddeley, 2003b). From the perspective of the literature on processing, the relationship follows from the claim that WM capacity predetermines the ability of processing syntactically complex sentences (Miyake, Carpenter, & Just, 1994). In light of this, it is not surprising that WM is a central topic also in aphasia research.

Despite the general agreement that WM limitations accompany linguistic deficits in individuals with aphasia (Goodglass, Gleason & Hyde, 1970; Gordon, 1983; Heilman, Scholes & Watson, 1976; Murray, 2012), the causal relationship between the two phenomena remains controversial. Several studies suggest that language impairment is a result of WM limitations (e.g. Miyake et al., 1994), while other studies claim that WM performance is affected because of linguistic deficits (Christensen & Wright, 2010; Mayer & Murray, 2012). A third group of researchers argue that both WM and linguistic symptoms are manifestations of a more general deficit (Burgio & Basso, 1997). A systematic literature review could shed light on the contradictory findings. So far, there have been literature reviews addressing WM and aphasia (e.g. Murray, Salis, Martin & Dralle, 2016; Wright & Fergadiotis, 2012; Wright & Shisler, 2005) but they address more specific issues, such as syntactic comprehension deficits in relation to WM limitations and the tests that are used to measure WM in individuals with aphasia. In order to understand the relationship between WM impairment and language deficits in aphasia, we review the relevant literature and propose a neurocognitive model that accounts for WM limitations in aphasia.

In the present paper we first briefly introduce WM, as it is currently understood, its relationship to language processing and the common methods specifically used for measuring WM in individuals with aphasia. Subsequently, we discuss the main findings of WM and aphasia studies. It is important to mention that our main focus is on studies where WM and linguistic measures were compared and not WM deficits in individuals with aphasia in general. Finally, we will present a neurocognitive model that accounts for WM and language deficits in aphasia.

2.2 WM and methods used for measuring WM

In many studies the terms WM and short-term memory (STM) are used interchangeably. However, there is a slight difference between the two phenomena. STM is defined as a passive storage for holding information for a limited amount of time, while WM is a system which not only stores information but also actively manipulates it (Daneman & Carpenter, 1980). Therefore, it is possible to assume that STM is the storage component of WM (Cowan, 2008). In the current paper we will use the term STM for the studies where the methods clearly measure only the storage component of WM and we will use the term WM if the method measures both the storage and processing components.

Various methods are used to measure WM and STM. However, because of the specificities of individuals with aphasia, not all existing methods of WM measurements are applicable to individuals with aphasia (Ivanova & Hallowell, 2012). The simplest one is the administration of different types of span tasks. A string of auditory or visual items is presented to the individuals with aphasia and they are asked to either repeat the string or to point to the corresponding images. The string may consist of digits, words, non-words, letters and other items. The digit span task is widely used to measure the phonological component of WM, while Corsi's spatial span task (Corsi, 1972) is suitable for the visuospatial component of WM, which does not necessarily include the language component of WM. It has been argued, however, that simple span tasks do not measure WM but rather STM, as there is no manipulation involved (Conway, Kane & Bunting, 2005).

Unlike forward span, backward span has a processing component and therefore it may be measuring WM. The participant is asked to repeat the string in reverse order. This method has been widely used in aphasia and early studies of WM (e.g. Murray, 2012; Lee & Pyun, 2014; Harnish & Lundine, 2014; Goodglass et al., 1970; Heilman et al., 1976; Saffran & Marin, 1975). Despite the similarity between forward and backward span tasks, the additional demand of manipulating the string and recalling in reverse order makes it a more challenging and a more specific measure of WM.

To measure WM accurately, it is necessary that the task contain both storage and processing components (Conway et al., 2005). Complex span tasks, introduced by Daneman and Carpenter (1980), are examples of such tasks. During these tasks, between the presentation and the recall of the span items, the participants are engaged in a different type of processing task, such as solving mathematical equations. Similar to the backward span, the reading and other complex span tasks measure both storage and processing components of WM.

The modified listening task (Ivanova & Hallowell, 2012) is a version of the reading span task (Daneman & Carpenter, 1980) but both passive and active recalls are measured at the end. First, pictures are presented and the participants are asked to recognize the ones corresponding to the words presented in between the sentences in the comprehension task (storage component). Then, they are asked to actively recall the words (processing component). To further develop WM measuring methods in people with aphasia, Ivanova and Hallowell (2014) introduced the eye movement WM task into aphasia studies. It is a variation of the modified listening task but, unlike the former, the participants do not have to give any response. Instead, they are instructed to look at the screen when the stimuli are presented, and their eye movements are recorded.

Yet another method of investigating WM is the implementation of *n-back* tasks (Kirchner, 1958). Several stimuli are presented to the participants and they are asked whether a certain item is the same as the one presented *n* items before, where *n* is normally a number between 1 and 3. Although various versions of *n-back* tasks are widely used in both aphasia and healthy brain research, it is not clear whether they measure exactly the same thing as complex span tasks. A study by Kane, Conway, Miura, and Colflesh (2007) demonstrated only a weak correlation between the *n-back* and operation span task (a variety of a complex span task) (Conway et al., 2005). In addition, Ivanova, Kuptsova & Dronkers (2017) showed a correlation between the *n-back* and the modified listening tasks in individuals with aphasia. However, only the latter was correlated to sentence comprehension measurements. They thus suggested that the two tasks measure different cognitive functions.

Despite the existence of various methods, it is important to consider that measuring WM in people with aphasia can be challenging for a number of reasons. They may, for example, have difficulties understanding the instruction or they may have auditory or visual impairment. People with aphasia also tend to show attentional deficits (Ivanova & Hallowell, 2012). Since according to the Baddeley & Hitch (1974) model, attention is one of the components of the WM system, its impairment may bias the measurement of the storage and processing components of WM. Moreover, it is difficult to separate language deficits and measure pure WM, as poor performance on various span tasks may not be due to WM deficits per se but rather the result of the fact that the individual with aphasia does not understand the task correctly or is not able to produce language correctly (Ivanova & Hallowell, 2012). An additional problem may be caused by the method itself. While several studies use simple span tasks and therefore measure the storage component of WM, others use complex spans, such as the reading span, or the *n-back* task. Therefore, the results from different studies may not be comparable. This issue will be addressed more thoroughly in the subsequent sections of this paper.

2.3 Working memory and general linguistic deficits in aphasia

Functional imaging studies suggest the involvement of Brodmann's (1905) area (BA) 9 and 46 in WM (Barbey, Koenigs & Grafman, 2013). BA 46 is located closely to BA 44, 45 and 47, which are known for their involvement in language processing (Price, 2010). Thus, it is not surprising that a lesion involving the language areas of the brain may affect WM as well.

In addition to that, WM models suggest a close relationship between WM and language processing. However, the exact role of WM in language processing remains controversial. Earlier, the linguistic component of WM was seen as a purely phonological storage (Baddeley & Hitch, 1974), while nowadays, as discussed, it is understood that the system is more complex than that. Based on brain lesion studies, several researchers (Friedmann & Gvion, 2003; Wright, Downey, Gravier, Love, & Shapiro, 2007) suggest that different types of verbal WM participate in phonological, syntactic and semantic processing (multiple resources), while others argue for a single computational system, covering multiple areas (a single resource) (Miyake et al., 1994).

A number of studies have shown that people with aphasia have WM limitations (Salis, Kelly & Code, 2015). Earlier it has been suggested that this might be connected to impairment in the phonological loop (Heilman et al., 1976). Later it has been shown though that the linguistic component of WM and the linguistic deficits occurring in aphasia are not merely phonological and that there is a complex interaction between WM and the language processing system (Martin & Saffran, 1997). As a result of a brain injury, WM storage becomes even more limited and language processing is impaired. However, it is still debatable whether the storage limitation and the language deficits are separate symptoms of brain injury or there is a causal relationship.

Based on a literature review, Wright & Fergadiotis (2012) conclude that in general people with aphasia do show lower capacity in WM than their matched non-injured individuals. But they suggest that this poor performance may be due to reduced linguistic abilities, rather than WM per se. Burgio and Basso (1997) tested individuals with left hemisphere brain injury and they showed that the WM deficits are present regardless of aphasia symptoms. Other studies have tried to show a relationship between aphasia severity and WM limitations (Christensen & Wright, 2010; Laures-Gore, Marshall, & Verner, 2011; Mayer & Murray, 2012). The findings are not uniform. In an *n-back* study using highly verbal and non-verbal stimuli Christensen & Wright (2010) found no correlation between the WM measurements and the Western Aphasia Test Aphasia Quotient (WAB-AQ) (Kertesz, 1982). However, in another *n-back* study Mayer & Murray (2012) found a correlation between non-verbal WM measurements and WAB-AQ. Interestingly, there was also a correlation between non-verbal tasks and the naming component of WAB-AQ, which raises the question whether the non-verbal *n-back* task was completely non-verbal or if language and WM share a common resource that are both lost to brain injury. Laures-Gore et al. (2011)

also observed a relationship between WM and WAB-AQ but they used digit forward and backward span tasks to measure STM and WM.

These discrepancies can perhaps be explained by the heterogeneity of the samples and the different methods chosen for measuring WM. In all three studies, although individual patients were classified according to aphasia type, they were treated as a single group. Furthermore, calculating WAB-AQ requires several measurements (e.g. naming, spontaneous speech measurements, syntactic comprehension, etc.). In general, the WAB-AQ involves both production and comprehension tasks, some of which may require less processing load than others. Therefore, it is possible that a certain component but not the entire quotient itself is related to WM. This could mean that WM limitations are related to some but not all aphasic symptoms. It could also mean that language and WM are affected and recovered differently in each individual with aphasia. We will discuss this issue in more detail in Section 2.6.

To solve the problem of measuring aphasia severity, Potagas, Kasselimis, and Evdokimidis (2011) developed a new scale for measuring aphasia severity. As a comprehension component they took the Greek adaptation of The Boston Diagnostic Aphasia Examination (BDAE) – Short Form (Tsapkini, Vlahou, & Potagas, 2010) sentence comprehension subtest, which consists of commands of various complexities. The production component consisted of the oral expressions subtest of the battery. They used the digit forward and backward span tasks to measure STM and WM respectively. Corsi's span was also administered to evaluate the spatial (non-verbal) component of WM. Aphasia severity was strongly correlated with both STM and WM. There was a weaker correlation between aphasia severity and spatial span. However, there was no correlation between spatial and verbal memory. They thus suggest that a common resource impairment causes both memory and language deficits in aphasia.

Likewise, Seniów, Litwin & Leśniak (2009) have shown not only a visuospatial STM impairment in individuals with aphasia but also a correlation between visuospatial span and BDAE subtests, such as naming and sentence comprehension. Lee and Pyun (2015) have gone further to examine the relationship between aphasia severity, STM and WM and the role of the right hemisphere lesion. They revealed that individuals with right hemisphere injury have similar cognitive deficits, as the ones with a left hemisphere injury, with the exception of digit forward span task. They also showed a correlation between all the STM and WM measurements (digit forward, backward, spatial forward, backward) and WAB-AQ, as well as its individual components, though the correlation was weaker in the case of the visual span measurements. Such findings (Potagas et al., 2011; Seniów et al., 2009; Lee & Pyun, 2015) suggest that while language and STM/WM have common resources, verbal short-term storage is related to language to a greater extent than the visuospatial one. The REF-model (Mogensen, 2011; 2014) provides an account for this phenomenon and it will be discussed later in this paper.

2.4 Working memory and specific linguistic deficits in aphasia

In this section we will discuss studies that have addressed the issues of WM limitations and specific linguistic deficits in aphasia. We will classify them based on the methods used for measuring WM and/or STM. Studies that used more than one method will be discussed in more than one subsection.

WM studies in aphasia have developed from simple observations of deficits in individuals with aphasia to complex explanations of the nature of the impairment and its link to other aphasia symptoms. These symptoms may be as specific as syntactic comprehension deficits or as broad as aphasia severity, which has both production and comprehension components.

2.4.1 Simple span tasks

Simple span tasks show that STM is limited in all aphasia types but to different extents, with individuals with Wernicke's aphasia being the most impaired (Baldo, Katseff, & Dronkers, 2012; Gordon, 1983; Kasselimis et al., 2013). Letter and digit span studies have shown impaired phonological storage in individuals with conduction aphasia (Gvion & Friedmann, 2012; Sakurai, Takeuchi, Kojima, Yazawa, Murayama, Kaga, Momose, Nakase, Sakuta & Kanazawa, 1998). Vallar, Bettac, Maria, and Silveri (1997) have described phonological limitations in an individual with mild agrammatism, too. In addition to auditory spans, they also used visual spans, demonstrating that visual performance is better preserved than auditory performance. Kasselimis et al. (2013), however, found no significant difference in forward and backward span performance between individuals with different lesion areas. The participants with aphasia performed worse than the control group, suggesting that WM limitations are related to the linguistic symptoms but they are not predetermined by the aphasia type.

Traditionally, researchers have tried to link WM limitations in aphasia either to general linguistic deficits or to syntactic comprehension impairment. Comprehension deficits may manifest themselves differently across aphasia types. An early attempt of classifying comprehension difficulties in aphasia was made by Goodglass et al. (1970). Their study included individuals with Broca's, Wernicke's, anomic, conduction and global aphasia and measured various types of comprehension. Contrary to their expectations, participants with Broca's aphasia did not show difficulties in comprehending prepositions or long and semantically rich sentences. Instead, they showed a poor performance in a pointing span test, which was significantly worse than that of individuals with other aphasia types. This finding led the authors to suggest that span tests have both comprehension and production components. The authors argued that individuals with Broca's aphasia show limited span performance because of their production deficits. They did not attribute the impaired span to storage limitations.

Caramazza and Zurif (1976), however, showed that individuals with Broca's aphasia do have comprehension deficits, which are different from what Goodglass et al. (1970) were looking for. Instead of using long and semantically rich sentences, they tested whether the participants were able to comprehend syntactically complex sentences, such as sentences with embedded clauses. They found that the individuals with Broca's aphasia rely on semantic information when trying to comprehend a sentence. The participants' performance was almost at ceiling level in syntactically simple sentences; while they showed impaired performance when syntactically complex sentences were presented. Semantic processing alone was not enough for comprehending such sentences. This finding led to a series of studies, investigating the relationship between syntactic comprehension deficits and WM limitations in aphasia. Those studies will be discussed below.

In order to show a relationship between syntactic comprehension impairment and WM deficits in individuals with Broca's and conduction aphasia, Heilman et al. (1976) ran an experiment using auditory and visual digit span and sentence comprehension tasks. They found no differences in digit span performance between the two groups of individuals. In a second experiment they showed a correlation between digit span and syntactic comprehension performance in individuals with both aphasia types. They suggested that these findings may be a result of Broca's aphasia and conduction aphasia involving the same underlying deficit, but they were reluctant to argue for causal relationships between the STM limitations and syntactic comprehension deficits.

The simple span tasks have also been used to demonstrate the existence of subtypes of

STM that may be impaired differently in different aphasia types. Friedmann and Gvion (2003) suggested that within verbal STM there may be different types of impairments present in agrammatic and conduction aphasia. Apart from digit, word and non-word span tasks they also used an *n-back* task to measure WM. According to their findings, syntactic comprehension was more impaired in agrammatic aphasia than in conduction aphasia, while STM/WM was more deficient in conduction aphasia. Moreover, they showed that phonological overload did not affect syntactic comprehension in either of these types of aphasia. These findings led to the conclusion that STM impairment alone does not play a role in syntactic comprehension deficits. Based on these results, the authors suggested that there are two types of WM, one of which they named syntactic and which was taken to be impaired in agrammatic aphasia. The other one was named phonological WM and was taken to be damaged in conduction aphasia. A later study including only individuals with conduction aphasia supported the idea that individuals with conduction aphasia have specifically phonological deficits and that the repetition problems present in conduction aphasia are a result of phonological store limitations (Gvion & Friedmann, 2012).

Phonological and syntactic components are not the only subdivisions proposed in the current understanding of WM based on its impairment in aphasia. Martin and Saffran (1997) suggested a separate STM for semantic information as well. They examined 15 individuals with aphasia, administering various verbal and non-verbal (i.e. visuospatial) WM and linguistic tasks. There was a double dissociation between semantically rich sentence comprehension and repetition. As a result, they suggested that there is a separate storage for semantic information, too, and that this can be separately impaired in aphasia. A later study by Martin and Ayala (2004) showed that lexical and semantic processes are involved in STM. In this experiment the participants with aphasia scored lower than normal in both visuospatial and verbal STM tasks but their visuospatial STM was more preserved. The authors are consistent in using only various types of simple span tasks to measure STM. Therefore, their focus is rather on STM, which is shown to be impaired in different types of aphasia.

2.4.2 Complex span

Complex span tasks have been used to study the single resource theory suggested by Miyake et al. (1994). This theory argues that the syntactic comprehension deficits present in aphasia are the result of constraints on WM capacity and of temporal constraints (i. e. capacity and duration). Using a reading span task, the authors assessed the WM capacity of a group of non-injured individuals. A sentence comprehension task with increasing syntactic complexity was presented at a speed faster than average speech rate. The results were comparable to those of aphasic findings (Caplan, Baker, & Dehaut, 1985). The participants with a lower capacity of WM performed worst on the most complex sentences. Based on these results, Miyake et al. (1994) supported the idea that syntactic comprehension deficits present in aphasia are a result of capacity impairment. Moreover, they suggested that sentence processing has a dynamic nature and depends on temporal constraints, which become more limited in aphasia.

Another example of the single resource view is a study by Sung, McNeil, Pratt, Dickey, Huka, Szuminsky & Doyle (2009). They studied sentence comprehension deficits connected to WM limitations in individuals with aphasia. For sentence comprehension they used the Computerized Revised Token Test (CRTT; McNeil, Pratt, Sung, Szuminsky, Ventura, Kim, Fossett, Doyle & Musson (2008)). Complex span tasks were administered to measure WM. They revealed that listening span measures predict sentence comprehension performance. Aphasia severity and sentence comprehension scores tended to be correlated with WM. Based on these findings, the authors concluded that WM limitations and general linguistic deficits share the same cognitive mechanisms. However, it is still unclear whether verbal WM deficits are just another measure of linguistic problems or if it is an impairment of its own and it is responsible for sentence comprehension deficits.

Caplan and Waters (1999) challenged the single resource theory of WM for both linguistic and non-linguistic tasks. They reviewed the literature and added their own studies, showing that sentence comprehension deficits are not always connected to WM limitations. The individuals with aphasia did not perform worse in the load condition. Moreover, individuals with dementia, who have significant deficits in executive functions, did not have difficulties comprehending syntactically complex sentences. These findings led the authors to conclude that separate cognitive resources are responsible for language interpretation and WM span. In this experiment, although the load condition was a complex span task, digits unrelated to the sentences were used to create additional load. It is therefore possible that indeed different resources were used here to process the sentences and the digits, while in the experiments mentioned above one resource was responsible for holding all the information.

The reading and listening span tasks were also used by Caspari, Parkinson, LaPointe, and Katz (1998) to show a correlation between WM deficits and aphasia severity. They concluded that linguistic deficits in aphasia may be a result of limited capacity in WM. They suggested that there is a trade-off between processing and storage. However, using the eye movement WM task Ivanova and Hallowell (2012) showed that there is no trade-off between processing and storage. In a follow-up study Ivanova, Dragoy, Kuptsova, Ulicheva and Laurinavichyute (2015) showed impaired WM span in both fluent and non-fluent individuals with aphasia. In addition, WM measurements correlated with the language comprehension measurements only in individuals with non-fluent aphasia, suggesting that a common resource is impaired in non-fluent but not fluent aphasia. In another experiment Ivanova et al. (2017) showed a correlation between the modified listening task and language comprehension measurements in non-fluent individuals with aphasia. Despite *n-back* measurements also being correlated to modified listening span measurements, they were not related to language comprehension.

Caspari et al. (1998) suggested that language itself facilitates WM processes and provides a larger storage for it. When linguistic deficits are present, WM capacity becomes limited and it has to rely to a great extent on non-verbal components of WM. Further studies, using *n-back* as a WM measurement method, have shown that non-verbal WM or its non-verbal components is more impaired in aphasia than its verbal counterpart (Christensen & Wright, 2010; Mayer & Murray, 2012).

2.4.3 N-back

Separating WM from language may be a challenge, as linguistic cues facilitate mnestic processes (e.g. rehearsal; Waugh & Norman, 1965). In order to minimize verbalization and to study WM as a separate function, Christensen and Wright (2010) used an *n-back* task to compare the WM of individuals with aphasia with that of non-injured individuals. They chose three groups of stimuli for the *n-back* task. The first group comprised fruits, which are semantically rich objects and easily verbalized. The second group consisted of the so-called fribbles, which are recognizable objects and nameable, although naming agreement does not always occur. Finally, they used block shapes as highly non-linguistic stimuli. As predicted, individuals with aphasia performed worse than intact matched controls in all *n-back* tasks. However, the two groups performed equally bad on the fribbles and shapes task. The authors explained these results by the slowing down of verbalizing processes in aphasia. A correlation between aphasia severity and WM deficits was not found.

In order to show the differences between verbal and non-verbal WMs, Mayer and Murray (2012) ran an experiment similar to the one described above. They used nameable and non-nameable stimuli in an *n-back* task and different WM load conditions. The individuals with aphasia showed greater deficits in the non-verbal type of the *n-back* task.

This finding supports the idea of Christensen and Wright (2010) that verbalizing abilities may be impaired in individuals with aphasia.

Among digit, word and non-word and listening span tasks, Friedmann and Gvion (2003) also used an *n-back* task to assess WM in individuals with agrammatism and conduction aphasia. The variation of the *n-back* task consisted of digits, short animal names and long animal names. In this study both individuals with agrammatism and conduction aphasia performed well on the *n-back* task and showed impairment in the span tasks. This finding confirms that the span and the *n-back* task measure distinct cognitive abilities.

2.5 The relationship between working memory limitations and language deficits in aphasia

The existing literature gives no clear-cut picture of the WM limitations and linguistic deficits in various aphasia types. This may be because every individual with aphasia is different from the other one and therefore it is a challenge to group them in an experiment. But it may also be because of certain limitations that most of these studies have.

An important limitation to most of the WM studies in aphasia is the heterogeneity of the aphasic groups. Although in most studies the participants are classified using different classification strategies (e.g. aphasia type or lesion localization) prior to the experiment, often they are all treated as one group and different inclusion criteria are used (e.g. Caspari et al., 1998; Mayer & Murray, 2012; Christensen & Wright, 2010; Laures-Gore et al., 2011; Caplan & Waters, 1999). Considering the various ways of categorizing the individuals with aphasia, the diversity of linguistic symptoms accompanying different aphasia types and the variety in lesion localization (and therefore the variety in lost neural substrate), this may be one of the reasons why the findings on WM and its relation to comprehension deficits in aphasia are heterogeneous. Therefore, based on the results presented in the literature it is not always possible to conclude whether a subtle deficit in the WM system is unique to a certain type of aphasia or lesion area or causes a certain aphasia symptom. The Reorganization of Elementary Functions (REF) model (Mogensen, 2011; 2014) presented in the next section provides an explanation of why considering the lesion localization is important and why the WM and language measurements may be drastically different between individuals with aphasia.

Not all studies have the limitations mentioned above. There are studies which take the locus of lesion into consideration and look for a relationship between WM deficits and the lesion area, rather than WM and aphasic symptoms (Baldo & Dronkers, 2006; Baldo et al., 2012; Burgio & Basso, 1997; Gordon, 1983; Kasselimis et al., 2013). Some of these studies try to answer the question whether or not WM deficits in individuals with a brain injury is related to aphasia (Burgio & Basso, 1997; Kasselimis et al., 2013), while others aim to find a possible connection between different types of WM deficits and the lesion location (Baldo & Dronkers, 2006; Baldo et al., 2012; Gordon, 1983). Studies which distinguish between different aphasia types showed relatively clear results. For instance, in conduction aphasia phonological storage problems were present, while in Broca's aphasia the deficits had a more syntactic nature (Friedmann & Gvion, 2003; Gvion & Friedmann, 2012; Sakurai et al., 1998).

Another limitation concerns the methods used for measuring WM. The three methods mentioned in this paper may not necessarily measure the exact same function and therefore the findings based on one method may not be generalizable to the WM system. Moreover, even within the same method different variations are used, which may further complicate the results (Wilms & Mogensen, 2011).

Although the linguistic impairment and WM limitation findings in individuals with aphasia are controversial, it is possible to summarize the existing views to create a point of departure for future studies. Based on the existing studies and findings, it is possible to categorize the positions on the link between WM and linguistic deficits in aphasia into three groups (Figure 2.1).

1. WM deficits cause language impairment. The single resource theory suggested by Miyake et al. (1994) falls into this category.

2. Language impairment causes WM deficits. The findings of Christensen and Wright (2010) and Mayer and Murray (2012) about the loss of verbalizing abilities in aphasia, as well as Wright and Fergadiotis (2012), support this idea.

3. WM and language are impaired independently in aphasia. The study by Burgio and Basso (1997) belongs to this group, as they showed that WM deficits are present in individuals with a left hemisphere brain injury independently of the presence of aphasia.

As discussed in the following section, the REF-model accounts for all of the possible scenarios mentioned above.

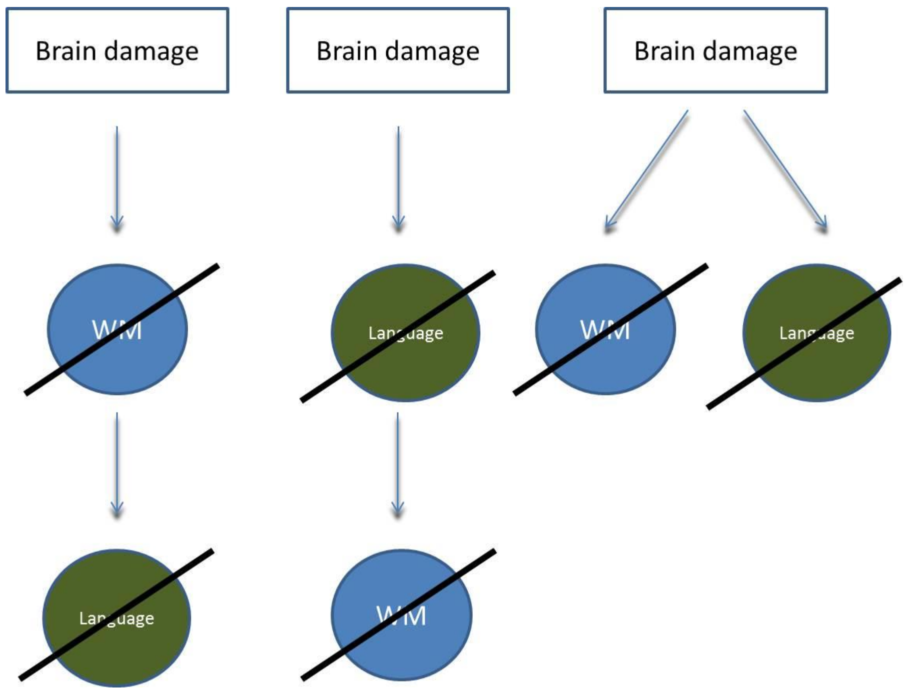

Figure 2.1 The three possible scenarios of language and working memory (WM) deficits as a result of a brain injury

2.6 The reorganization of elementary functions

The reorganization of elementary functions (REF) model (Mogensen, 2011; 2014) positions itself between domain generality and specificity and provides possible explanations of the WM and language deficits that occur after brain injury. The model consists of four levels: elementary functions (EF), algorithmic modules (AM), algorithmic strategies (AS) and surface phenomena (Figure 2.2). The lowest level of the model consists of EFs. They are the only ones that are truly anatomically localized and highly modular. EFs are not traditionally defined cognitive functions. Rather, an EF contributes a specific and rather basic information processing. As a 'fixed information processing module' most EFs will simultaneously contribute to many of the traditionally defined cognitive functions. The top level comprises surface phenomena, which are observed at a behavioural level (e.g. *n-back* task performance). EFs interact and through experience and learning the connectivity and interaction between EFs are modified. Via experience and the feedback created during attempted problem solving EFs are combined into ASs (see e.g. Mogensen, 2014). AMs (e.g. temporary storage) emerge as 'common mechanisms' within ASs. Each AM or AS has a specific neural substrate – however, that neural substrate is distributed in the form of the neural substrates of the constituent EFs and their interconnections. A single AS is the basis for a surface phenomenon. AMs on their own, however, cannot result in a surface phenomenon. An EF may be part of more than one AM and thus when it is lost to injury, more than one AM/AS will suffer and more than one impaired surface phenomenon may be observed.

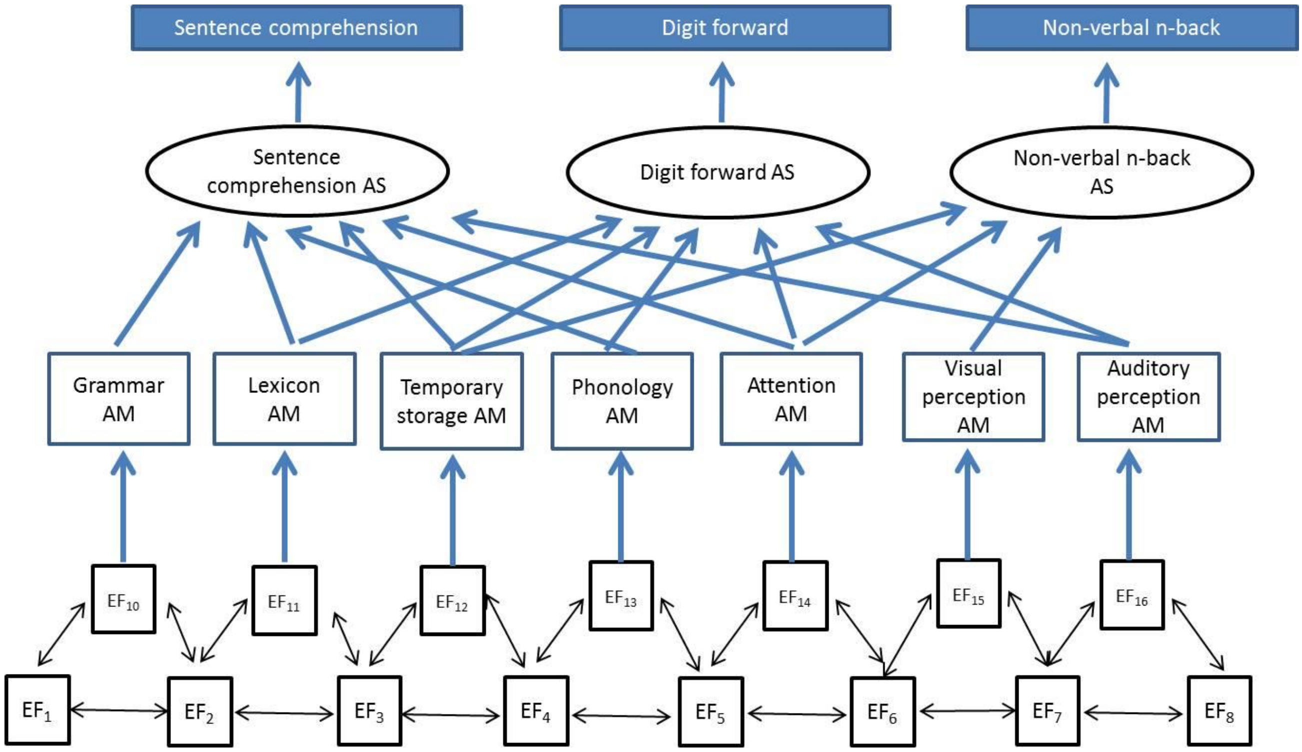

Figure 2.2 The simplified version of the REF-model in a non-injured brain: elementary functions (EFs) interact to create algorithmic modules (AMs), which in turn result in task-specific algorithmic strategies (ASs). The ASs program the surface phenomena of corresponding cognitive functions, which can be observed at a behavioural level.

When brain injury occurs, certain EFs are irreversibly lost (Figure 2.3a). The post-injury symptoms observed are due to the loss of ASs that are supported by the lost EFs. Nevertheless, through experience (including therapeutic training) the existing EFs reorganize to create new ASs, which then serve as basis for surface phenomena apparently similar to the ones lost to injury (Figure 2.3b). Those new surface phenomena, however, are not identical to the pre-injury ones. Therefore, the observed symptoms are also due to 'recovered' surface phenomena.

The REF-model may contribute to a better understanding of the language and WM impairments described above. In the context of the REF-model it is possible to understand how all the scenarios mentioned in the previous section are equally plausible in brain injury - depending on which AMs are disrupted due to the loss of underlying EFs, how many EFs are lost, what direction the reorganization of EFs take, as well as the pre-injury experience of the injured individual.

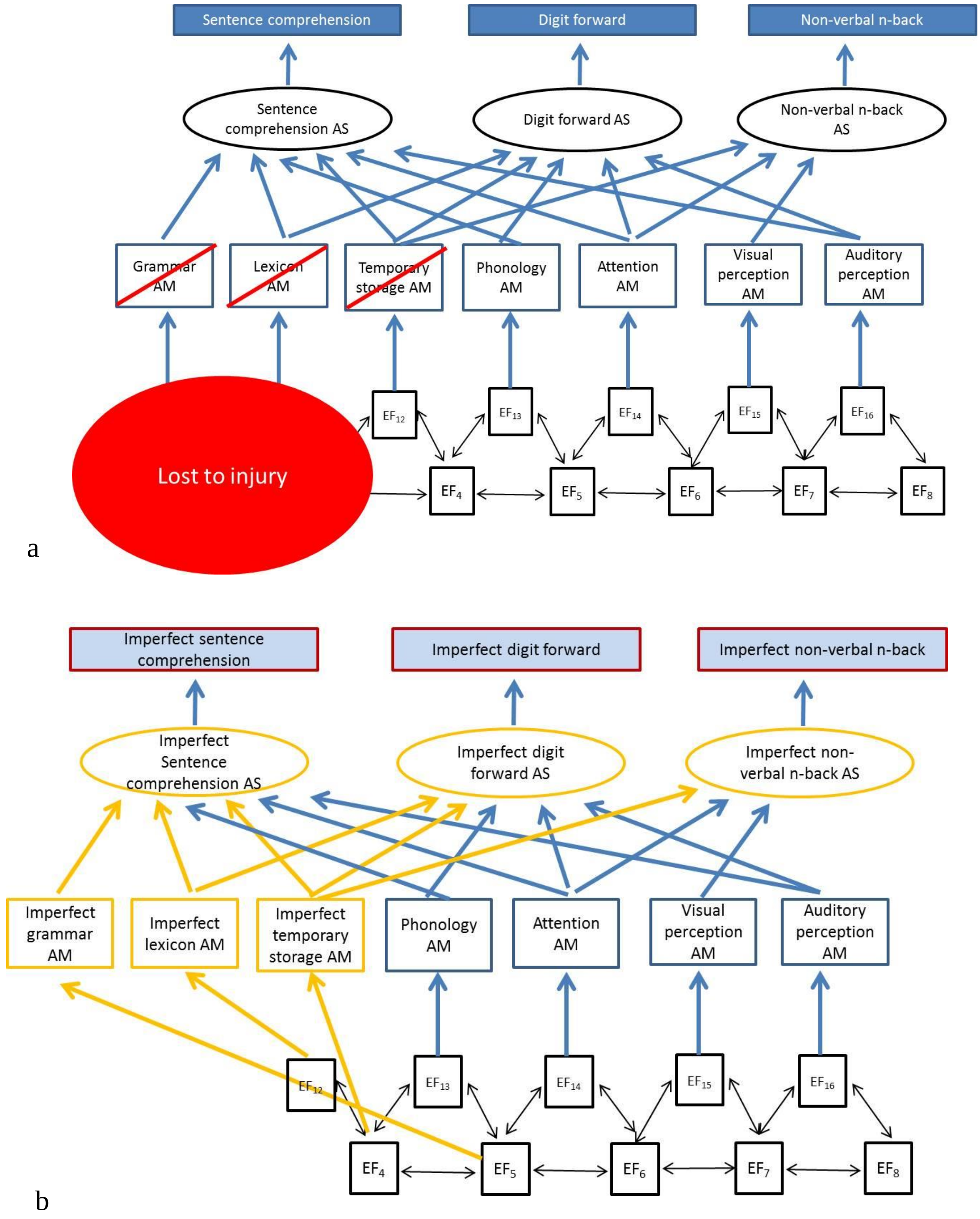

Figure 2.3 The simplified REF-model following an injury. a. Several elementary functions (EFs) are lost to injury and thus the corresponding algorithmic modules (AMs) and strategies (ASs) are also lost. b. As a result of reorganization of EFs, new albeit imperfect AMs are formed, which in turn result in imperfect ASs that can be observed as imperfect performance at a surface level.

The REF-model suggests that WM as an independent cognitive function does not exist but rather there are task-specific ASs, which are used to perform various WM tasks. Depending on the number of shared AMs, certain WM measurements may or may not be correlated. As brain injury occurs, the acute symptoms are the ones that are a direct consequence of lost EFs and disrupted ASs. As the individual progresses to the chronic stage, the reorganization occurs and the symptoms observed are a result of the new imperfect ASs. This is when depending on which EFs are lost and how the remaining ones are reorganized, we observe different symptoms. If, for instance, EFs underlying the phonology AM are lost, at surface imperfect phonology will be observed both in language (e.g. impaired repetition in conduction aphasia) and digit span tasks but not Corsi's span. But if the brain injury affects the EFs underlying the temporary storage AM, more general symptoms, such as high aphasia severity, as well as poor performance in every STM and WM task will be observed. If, on the other hand, the EFs underlying the sequential processing AM are affected, STM measures will remain relatively intact, while brain-injured individuals will have difficulties performing complex span tasks and will produce and comprehend relatively simple sentences (symptoms of agrammatism).

The REF-model also emphasizes the methodological importance of taking into account aphasia type and both the language and WM tasks used for measuring linguistic and WM performance. Depending on the specific task, different sets of AMs may interact to create a specific AS for the task. Also, the lesion location determines the sets of EFs that are lost to injury and thus to some extent it is determined which AMs and ASs are impaired. Ivanova et al.'s (2017) study is a good example of this. Non-fluent individuals with aphasia show a correlation between comprehension and listening span, while the same correlation is not observed in the fluent group. This may be an indicator that non-fluent individuals lose shared EFs of language comprehension and modified listening span task ASs, while fluent patients lose EFs that are still underlying the language comprehension and modified listening span task ASs but they are not shared.

On top of the above-mentioned, individual differences also come into play. The REF-model suggests that AMs are created as a result of experience and learning. Each individual goes through different sets of experiences and learning and therefore their pre-injury AMs may be different from those of other individuals. Thus, the WM and language interactions in individuals with aphasia drastically differ from one another.

2.7 Summary

There is a huge amount of literature dedicated to aphasia and WM/STM. Undoubtedly, along with linguistic deficits WM is also impaired in different types of aphasia. However, the findings are controversial and it is not possible to draw firm conclusions about the exact interaction between language and WM in different types of aphasia because of the different methods used for measuring WM and STM and because all types of aphasia are treated as one group. The REF- model suggests an explanation for those findings. In particular, the loss of specific neural substrate and unique recovery mechanisms result in various types of interactions between WM and language, where in some cases WM may be language-dependent and in other cases language independent - depending on the type of the lesion and the tasks being used for measuring WM/STM and linguistic symptoms. Thus, we emphasize the importance of considering the choice of the WM measurement task, the language evaluation test and aphasia type when conducting a study about WM and language deficits in individuals with aphasia.

CHAPTER 3

Grammatical and lexical pronoun dissociation in French speakers with agrammatic aphasia: a usage-based account and REF-based hypothesis

3.1 Introduction

3.1.1 Pronouns in agrammatism

Agrammatism is defined in terms of omissions and substitutions of grammatical items (Goodglass, 1997). It may appear as a result of a brain injury and often accompanies Broca's aphasia (Druks, 2016). Among other symptoms speakers with agrammatism are said to have trouble producing function or closed-class words, while content or open-class words are generally preserved (Tissot, Lhermitte & Mounin, 1973).

Pronouns belong to closed classes and are thus expected to be affected in agrammatic production (Druks, 2016). Indeed, crosslinguistic studies have shown that individuals with agrammatism produce fewer pronouns than non-injured controls (French: Nespoulous, Dordain, Perron, Jarema & Chazal, 1990; Italian: Miceli & Mazzucchi, 1990; Swedish:

Månsson & Ahlsén, 2001; Greek: Stavrakaki & Kouvava, 2003; Spanish, Catalan & Galician: Martinez-Ferreiro, 2010; Danish: Brink, 2014). Pronouns are, however, less affected than other categories in agrammatism (De Roo, 2002), which may indicate that they either have a unique position between function and content words or that various types of pronouns are affected differently in agrammatism.

Previous studies suggest that not all pronouns are equally impaired in agrammatic production. Clitic pronouns have been shown to be particularly sensitive to brain damage (Lonzi & Luzzatti, 1993; Stavrakaki & Kouvava, 2003; Chinellato, 2004, 2006; Rossi, 2007). Additionally, object clitics are more prone to omission than subject clitics (Nespoulous, Dordain, Perron, Ska, Bub, Caplan, & Lecours, 1988; Stavrakaki & Kouvava, 2003; Nerantzini, Papadopoulou & Varlokosta, 2010), while indirect object clitics are omitted more often than direct object clitics (Rossi, 2007).

Direct object clitics (1) have also been shown to be more sensitive to damage than reflexive clitics (2) (Martinez-Ferreiro, 2010; Sanchez-Alonso, Martinez-Ferreiro & Bastiaanse, 2011). Sanchez-Alonso et al. (2011) have further shown that Spanish speakers with agrammatism have more problems producing the "unaccusative" form of the clitic *se,* (3) than its reflexive counterpart (1). Moreover, object clitic pronouns are often either substituted with a full noun phrase or they occur together with the noun phrase in the same utterance (Sanchez-Alonso et al., 2011; Martinez-Ferreiro, Reyes & Bastiaanse, 2014)

(1) La niña ***se*** *lava.*

'The girl washes herself.'

(2) La niña ***la*** *abre.*

'The girl opens it.'

(3) La puerta ***se*** *abre.*

'The door opens.'

Despite subject pronouns being less affected than object pronouns, a dissociation between clitic and non-clitic subject pronouns has been attested in Italian and French agrammatic speakers (Nespoulous et al., 1990; Chinellato, 2004, 2006): agrammatic speakers tend to omit clitics more often than their non-clitic counterparts. Interestingly, clitic subject pronouns are obligatory and have a higher frequency than their non-clitic counterparts (Schmitz & Müller, 2008).

Pronoun comprehension has also been shown to be impaired in agrammatism (Jarema & Friederici, 1994). In particular, French speakers with agrammatism have more difficulties comprehending direct object pronouns than homonymous articles (*le*, *la*). However, in general the dissociation between different types of pronouns is less evident in comprehension studies. Friederici, Weissenborn & Kail (1991) have described a relatively preserved comprehension of direct and indirect object pronouns in three different languages. Additionally, Bos, Dragoy, Avrutin, Iskra and Bastiaanse (2014) have shown that direct object pronouns and reflexives are equally preserved in Russian speakers with agrammatism. The authors did find, however, that individuals with agrammatism were better at comprehending 'who' pronouns than 'which' pronouns.

3.1.2 Hypotheses accounting for pronoun impairment dissociation patterns: the variability and dissociation issue

The above findings witness several specific dissociations that have been accounted for in different ways. Avrutin's (2006) "weak syntax" theory accounts for the dissociation between direct object pronouns and reflexive pronouns in agrammatism. The theory suggests that pronouns with extrasentential reference, such as direct object pronouns, require higher processing load than pronouns with intrasentential reference, such as reflexive pronouns. Consequently, individuals with agrammatism, having processing limitations, omit the direct object pronoun or substitute it with a full noun. At the same time, pronouns with intrasentential reference are less costly to process and therefore they are less problematic for individuals with agrammatism.

Another type of dissociation between clitic and non-clitic pronouns has been associated with impaired verb processing. Verb production has been shown to be impaired in agrammatism (Bastiaanse & Jonkers, 1998). Since, in the Romance languages investigated, clitic pronouns are dependent on verbs (Kayne, 1975), one might consider whether the dissociation between clitic and non-clitic pronouns is a result of verb production problems. In fact, speakers with agrammatism tend to omit subject pronouns in utterances where the verb is non-finite or altogether omitted (Kolk & Heeschen, 1990; De Roo, 2002). Kolk & Heeschen (1990) attribute this finding to the adaptation of processing limitations, while De Roo (2002) argues that subject pronouns are omitted because the untensed verb fails to assign nominative case to the subject pronouns. In her study, however, there are occasional occurrences of subject pronouns in non-finite utterances and omissions in finite utterances, indicating variability even within participants.

It is commonly agreed that agrammatic speech differs both across individuals and across tasks (Miceli, Silveri & Romani, 1989; Tesak, 1992; Sahraoui & Nespoulous, 2012;

Sahraoui, 2015). One of the reasons for this variability could be different adaptation strategies that individuals with agrammatism use, such as ellipsis (Kolk & van Grunsven, 1985; Kolk, 1995). In terms of variability, pronouns are no exception. Sanchez-Alonso et al. (2011) showed that speakers with mild agrammatism are more prone to substitute clitic direct object pronouns with another clitic or a full noun phrase, while the more severely impaired ones omitted clitic direct object pronouns. They suggested that speakers with mild agrammatism are better at handling the higher processing load.

The number of attested instances of pronoun dissociations in agrammatism raises the question whether the premises for associating impairment of pronouns *en bloc* with agrammatism are inaccurate. We believe they are, and that pronoun dissociations should be expected. The term *agrammatism* reflects an understanding that there is something about grammar (as opposed to other aspects of language, such as lexicon) that is particularly difficult for individuals with the relevant kind of aphasia. The definition poses a problem, however, as grammatical items are themselves poorly defined. Grammatical words are often contrasted with lexical words, but as pointed out by Geurts (2000), among others, the distinction between grammar and lexicon has for a long time remained pre-theoretical and intuition-based. This entails that theoretically based criteria for classifying words as grammatical have been absent. Definitions in terms of closed- vs. open-class words or form or function vs. content words are an attempt to circumvent this problem, but instead they add new problems. In particular, what belongs to closed classes is a highly language-specific matter. In standard average European languages, for instance, verbs belong to open classes, but in other languages they belong to closed classes. Cases in point are found in the Trans New Guinea language family, in languages such as Kalam, Kobon and the Chimbu-Wahgi languages, all of which have only between 60 and 150 inflecting verbs (Pawley, 2006). Therefore, a link between grammar and closed classes cannot be maintained. Therefore, there is no reason to expect closed-class words like pronouns to behave in a uniform way in agrammatism. Friederici (1982) showed that German prepositions when used grammatically as obligatory parts of syntactic structures were more severely affected in agrammatic speech production than when used lexically. There is no reason to exclude a similar dissociation in pronouns.

In this paper, we investigate whether (in addition to the dissociations discussed above) there is evidence for such a dissociation between grammatical and lexical pronouns. We base our distinction between grammatical and lexical pronouns on a novel theory of grammatical status and grammaticalization (Boye & Harder, 2012; see Helbig & Buscha, 2001, and Eisenberg, 2004 for related proposals pertaining specifically to German pronouns), and test whether this distinction is reflected in a pronoun dissociation in French agrammatic speech.

In addition, we suggest a neurocognitive account for variability across individuals with agrammatism. In this paper we introduce the Reorganization of Elementary Functions (REF) model (Mogensen, 2011, 2014), which may entail a possible explanation for variability of impaired pronoun processing across individuals with agrammatism.

In the next sections we will discuss the two theoretical bases of our predictions. We first present the theory of grammatical status (Boye & Harder, 2012), which will be used to reclassify pronouns. We then proceed to the REF-model (Mogensen, 2011, 2014). Afterwards we briefly discuss French pronouns from the Boye & Harder (2012) point of view. Finally, we present our aims and hypotheses before proceeding to the methodology and results.

3.1.3 A usage-based theory of grammatical status

As discussed above, the distinction between grammar and lexicon has for a long time remained pre-theoretical and intuition-based. This entails that theoretically based criteria for classifying words as grammatical have been absent.

Generative Grammar in principle offers a solution to this, but with its focus on syntactic structure, it is not ideally equipped for dealing with the distinction between grammatical and lexical words, and often resorts to the problematic distinction between closed and open word classes (Harley, 2006).

A functionalist and cognitivist alternative is Boye & Harder's (2012) usage-based theory of grammatical status[1]. This theory offers an account of the relation between lexicon and grammar (evidenced by grammaticalization processes by which lexical items give rise to grammatical ones), which entails an explanation of why grammatical items are cognitively difficult in a way that lexical items are not. The central idea of Boye & Harder (2012) is that

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[1] Boye & Harder's (2012) theory is compatible with different functional-cognitive frameworks, including Cognitive Grammar (Langacker, 2008), Role and Reference Theory (Valin & LaPolla, 1997); Functional Grammar (Dik, 1997), Functional Discourse Grammar (Hengveld & Mackenzie, 2008); cf. Sahraoui (2015) on the relevance of functionalist approaches to agrammatism.

grammatical items cannot convey the main point of an utterance, but are by convention ancillary, providing secondary information. In contrast, lexical items have the potential to convey the main point of an utterance; they are by convention potentially primary. This defining property entails that grammatical items are inevitably dependent on other items, while lexical ones are not necessarily so. Being secondary by convention, grammatical items need to co-occur with other items, in relation to which they are secondary. They cannot stand alone (cf. the fact that you cannot, outside metalinguistic or contrastive contexts, produce the article *the* or the past tense suffix *-ed* in isolation). In contrast, lexical items, as potentially primary, have the potential to stand alone (*Fire!, Run!*).

The defining property also entails a difference between grammatical and lexical items when it comes to focalizability. Focus has the effect of singling out the most prominent element in an utterance. Since only lexical elements can potentially be the most prominent element in an utterance (outside metalinguistic and contrastive contexts), only they can be focalized. Grammatical expressions, unlike lexical expressions, cannot be focalized, for example, by means of clefting or focalizing particles. This means that non-focalizability is a criterion for grammatical items, whereas focalizability is a criterion of lexical status.

To give an example of how this criterion works, compare the English pronouns *it* and *him* in the construction *Sue likes it/him*. By the above criterion, *it* comes out as grammatical. It cannot be focalized by means of clefting (4) or by means of a focus particle such as *only* (5), and even stressing it seems odd (at least outside a metalinguistic context) (6).

(4) **It is it that Sue likes*.

(5) **Sue likes only it.*

(6) ?*Sue likes IT.*

In contrast, *him* comes out as lexical. It can unproblematically be focalized by means of clefting (7), a focus particle (8) or stress (9).

(7) *It is him that Sue likes*.

(8) *Sue likes only him.*

(9) *Sue likes HIM.*

French differs from English in having more grammatical pronouns. In section 1.4 we outline how we classified French pronouns based on the criterion discussed above.

3.1.4 The REF-model

The REF-model offers a novel view of neurocognitive organization and suggests a mechanism for recovery after a brain injury (Mogensen, 2011, 2014). The model has three levels: Elementary Functions (EFs), Algorithmic Strategies (ASs) and Surface Phenomena. It is at the level of Surface Phenomena that traditionally defined functions, such as language or memory, are manifested. The results of post-injury recovery of language can also be observed at the Surface Phenomena level.

Out of the three levels of the REF-model only the EFs (the lowest level) are truly anatomically localized and highly modular. When brain injury occurs, EFs are irreversibly lost and consequently their functions are also lost. EFs, however, are not cognitive functions in the traditional sense (e.g. no individual EF mediates phonology or syntax). The functions (or information processing) of individual EFs should rather be described using mathematical terms.

The mid-level of the REF-model comprises ASs. Each AS consists of interacting EFs. ASs are formed as a result of experience and learning. Unlike EFs, ASs are spread across different brain regions. The activation of several related ASs may lead to Surface Phenomena that are equally proficient and apparently similar. Functional impairment may be observed after brain injury, if the ASs underlying the Surface Phenomena are compromised by brain injury. This happens because the neural substrate of the EFs composing the AS is lost.

In order to recover the impaired function, the brain will need new ASs, which involves the "Reorganization of Elementary Functions" (REF) process. The existing EFs, which previously may have not been involved in a function, unite to form a new AS. The "recovered" function will not be identical to the pre-injury one. Moreover, the function may vary in different individuals. Besides the extent of the neural loss, two factors have a major impact on the post-injury development of new ASs: (1) the post-injury experience of the patient and (2) the pre-traumatic pattern of connections between EFs – a pattern mainly determined by the pre-traumatic experiences of the patient. In the case of language, post-injury experience could involve practicing language both in a therapeutic setting and in daily life. The variety of experiences may result in variability of post-injury performance across individuals with agrammatism. It could be the case that the new adaptive strategies which the individuals with agrammatism use to cope with the deficit are the result of a new, albeit impoverished or imperfect grammar.

Regarding the present issue of pronoun dissociation in agrammatism, the REF-model agrees with the predictions of the usage-based theory of grammatical status (Boye & Harder, 2012). According to the REF-model (Mogensen, 2011, 2014) the normal development of the neurocognitive mechanisms underlying a given cognitive domain (e.g. grammar) is the result of function-and-experience-driven establishment of networks of EFs. Thus, the networks representing a given class of words (e.g. pronouns) will depend on the function of these words in the language in question. If, in a given language, pronouns can both serve in a grammatical and a lexical role, the REF-model predicts that this functional dissociation will also lead to a differentiation into different networks representing grammatical and lexical pronouns, respectively. Consequently, like the theory of grammatical status, the REF-model predicts that grammatical and lexical pronouns will be differently impaired in agrammatism.

3.1.5 Pronouns in French

We used the focus test introduced in Section 1.2 above to classify 137 French pronouns as grammatical or lexical. We included the following types of pronouns: clitic personal pronouns (e.g. *je, tu, il*), non-clitic personal pronouns (e.g. *moi, toi, lui*), adnominal demonstratives (e.g. *ce, c', cette*), free-standing demonstratives (e.g. *celui, celle*), adnominal possessive pronouns (e.g. *mon, ton, son*), free-standing possessive pronouns (e.g. *le mien, le tien, le sien*), indefinite pronouns (e.g. *on, tout le monde, quelqu'un*), interrogative pronouns (e.g. *qui, qu'est-ce que*), and relative pronouns (e.g. *qui, que, dont*). Some of these form homonymous pairs, which can, however, be distinguished on distributional grounds. For instance, the interrogative pronoun *qui* can be found in main clauses, while the relative pronoun is found in subordinate clauses. One type of pronouns, the adnominal possessive pronouns, are traditionally referred to as possessive adjectives (*adjectifs possessifs*) in Romance linguistics, rather than as pronouns (but see also e.g. Franks & Schwartz, 1994 on the classification of these forms as pronouns). However, this is a purely terminological issue. The relevant items (e.g. *mon, ton, son*) distributionally and semantically correspond to items classified as personal pronouns in other languages (e.g. English *my, your, his*), and like the rest of the items included as pronouns in the present paper, they meet a standard definition of pronouns as items that have no descriptive content, but are used to refer anaphorically to NPs and/or deictically to entities in the extralinguistic context (Matthews, 2007).

Based on the focus test, the pronouns were classified as shown in Table 3.1 (see Appendix B for the full list).

The distinction between grammatical and lexical pronouns can be exemplified by the contrast between *il* and *lui*, both 3rd person masculine pronouns. *Il* cannot be focalized, for instance in a cleft construction, as illustrated in (10), but *lui* can, as illustrated in (11).

Table 3.1 Classification of French pronouns using the focus test

Grammatical pronouns	**Lexical pronouns**
clitic personal pronouns (e.g. *je, tu, il*)	non-clitic personal pronouns (e.g. *moi, toi, lui*)
adnominal demonstratives (e.g. *ce, c', cette*)	free-standing demonstratives (e.g. *celui, celle*)
adnominal possessive pronouns (e.g. *mon, ton, son*)	free-standing possessive pronouns (e.g. *le mien, le tien, le sien*)
non-focalizable indefinite pronouns (*on*)	focalizable indefinite pronouns (e.g. *tout le monde, quelqu'un*)
relative pronouns (e.g. *qui, que, dont*)	interrogative pronouns (e.g. *qui, qu'est-ce que*)

(10) **C'est **il** qui mange une pomme.*

Intended reading: 'It is **he** who eats an apple.'

(11) *C'est **lui** qui mange une pomme.*

'It is him who eats an apple.'

In fact, *lui* can be used to focalize reference to a 3rd person masculine entity (12).

(12a) ***Lui**, **il** mange une pomme.*

'Him, he eats an apple.'

(12b) ***Lui** mange une pomme.*

'Him eats an apple.'

This means that according to the focus criterion, *il* comes out as grammatical, while *lui* comes out as lexical. In the third example, the focusing and stressed pronoun *lui* in an appositive construction (6b) or as a pronoun in the place of *il* (equivalent to *he* in English) is commonly used in spoken French. In 6b, the focus is on *lui* as one of the entities previously introduced in discourse or in the context, contrasting with some another entity.

Il is often referred to as a weak or clitic pronoun, while *lui* is strong or non-clitic. According to the focus criterion, all weak French pronouns (including also *je, me, tu, te, ils*) are grammatical, while all strong ones (including also *moi*, *toi*, *eux*) are lexical. Some pronouns (including *elle*, *nous*, *vous*) have both a weak and a strong variant. In the written language at least, these can be distinguished only on distributional grounds. For instance, in (13), the first instance of *elle* is strong (stressed, focalized) and the second weak.

*(13) **Elle**, **elle** mange une pomme.*

'She eats an apple.'

Thus, we classified pronouns like the first one in (13) as lexical, and pronouns like the second one in (13) as grammatical.

In the case of personal pronouns, then, our classification is coextensive with traditional distinctions between clitic and non-clitic or between weak and strong pronouns. In the case of possessive pronouns, similarly, our classification may be seen as coextensive with traditional distinctions between 'possessive adjectives' and possessive pronouns proper. The classification we suggest brings these two traditional distinctions under the grammatical-lexical distinction as a common umbrella, which in addition covers three other distinctions (see the five distinctions in Table 2.1).

3.1.6 The predictions of the current study

Based on the Boye & Harder (2012) theory and the diagnostic criteria of grammatical and lexical status that go with it, we predict that grammatical pronouns are more severely affected than lexical ones in agrammatic connected speech. So far, this theory has only been tested in a case study of a Danish speaker with agrammatism, showing that grammatical pronouns are more impaired than the lexical ones (Brink, 2014). We further test this prediction in a study of French speakers with agrammatic aphasia. In order to investigate the possibility that impaired production of grammatical pronouns is merely an effect of impaired verb production (as some grammatical pronouns are enclitic on verbs), we also conduct an analysis of verb-pronoun combinations.

The current study has both linguistic and psycholinguistic implications. From the linguistic point of view, the distinction suggested in Boye & Harder (2012) between grammatical and lexical pronouns is at odds with the traditional view of pronouns according to which all pronouns are grammatical. This means that if we show dissociation between the two kinds of pronouns in agrammatic speech, the linguistic theory will have better predictive power as an account of grammatical status than other theories, such as generative theories that define grammatical words as words belonging to closed classes (Harley, 2006).

The psycholinguistic implication is that this study may provide evidence for distinct processing patterns between grammatical and lexical items, evidence that would set new directions for psycholinguistic research.

We hypothesize that speakers with agrammatism produce fewer grammatical pronouns than lexical ones because grammatical pronouns according to Boye & Harder (2012) are discursively secondary, and therefore are omitted more often than the lexical ones in agrammatic production, when processing load is limited. We also expect more substitutions of grammatical pronouns than of lexical ones. In terms of adaptive strategies, we predict that individuals with agrammatism will rely more on fixed expressions or will build up their own unique strategies to cope with the deficit. For that reason, after a detailed quantitative analysis, we will provide an analysis of the relationship between pronoun and verb production.

3.2 Method

In order to test our hypothesis, we used the transcribed and pre-processed data of Sahraoui (2009) and Sahraoui & Nespoulous (2012).

3.2.1 Participants

The speech samples were obtained from six speakers with agrammatism (aged between 41 and 56, 5 males, 1 female, 1-9 years post-onset) and nine non-injured controls (aged between 32 and 61, 6 males, 3 females), all of them native speakers of French. All of the speakers with agrammatism had a lesion as a result of a left hemisphere stroke leading to Broca's aphasia. The aphasia type and the severity were determined by a speech and language pathologist. Based on fluency, four of the participants were classified as having severe aphasia (words per minute 25–38; mean length of utterance 3,7 – 6,8) and two of them as having mild aphasia (words per minute 66 and 68; mean length of utterance 9,7 and 9,9 respectively). Information about the individuals with agrammatism (handedness, etiology, education and diagnosis) and speech samples can be found in Appendix A.

3.2.2 Materials & Procedure

Connected discourse was elicited in three production tasks, gradually increasing the constraints. In the first task the participants were asked to talk about his or her history of illness (autobiography). In the second task the participants were asked to retell the well-known fairy tales Cinderella and Little Red Riding Hood (narrative speech). In the third task unknown sequences of four pictures were presented to the participants and they were asked to construct a story (descriptive speech). The sample size, words per minute (WPM) and mean length of utterance (MLU) per task can be found in Appendix A. For detailed information about the data see Sahraoui (2009) and Sahraoui & Nespoulous (2012).

3.2.3 Pronoun count and scoring

As discussed above, 137 French pronouns were classified as grammatical or lexical based on Boye & Harder's (2012) focus criterion (see section 3.1.4 for details).

A potential confounding factor when comparing the occurrence of simple expressions such as pronouns is the fact that pronouns may be part of larger 'fixed phrases', i.e. idioms or constructions that are lexicalized as whole units (for examples, see the discussion below). Such larger units may be stored and retrieved as unitary lexical items (or holophrases). The pronoun forms that enter into such units would not be predicted to have occurrence patterns reflecting their properties as either grammatical or lexical pronouns, but would be expected to be merely side effects of the choice of the larger units as such. If so, raw occurrences of pronoun expressions contained as parts would not be relevant for throwing light on the differences between grammatical and lexical pronouns in aphasic speech. In addition, people with aphasia may rely more than controls on fixed phrases, precisely because freely constructed combinations present problems for them.

In order to counteract this potential source of error, we attempted to provide figures that did not include pronouns occurring in such fixed phrases. This raises problems of identification, since there are no clear-cut criteria for separating cases where properties of the larger units override all properties of internal parts; the concept of 'partial compositionality' as invoked by Langacker (1987) reflects the existence of a grey zone where some properties are compositional (and hence reflect the properties of the smaller components) while other properties are due to the combination rather than the components. What is more, one man's fixed phrase may be another man's freely constructed combination.

We chose the following procedure: from the corpus we selected a number of collocations containing pronouns that appeared as plausible candidates for being 'fixed phrases' in a broad sense. Within that group, we identified those in which phrasal meaning did not include those functions that are associated with standard pronoun meanings: deictic or anaphoric reference. For instance, the expression *ça va* (a greeting, lit: 'it goes') we classed as a greeting that did not involve identification of a deictic referent for *ça*, and *il* in the phrase *il faut* we similarly classed as an impersonal verb construction that does not involve anaphoric reference. A list of the expressions we removed as part of this operation are the following: *c'est ça* ('that's it'), *il faut* ('it is necessary'), *il paraît* ('it seems'), *il semble* ('it seems'), *s'en aller* ('to leave'), *ça va* (a greeting, lit: 'it goes'), *ça veut dire* ('it means'), *il y a* ('there is').

In contrast, we did not exclude either the deictic or the anaphoric pronoun in the collocation *ça c'est* (‘it is’), since both occurrences arguably involve picking out a referent. The selection was independently checked by two French linguists.

For the current study we first included all the pronouns in the count, except for the ones that were purely conversational fillers (such as sentences ending in *quoi* (‘what’)). We then did a separate count, excluding pronouns occurring in fixed expressions based on the selection mentioned above. A total number of 139 elements from the agrammatic samples and 254 elements from the control samples were excluded. In order to calculate the number of grammatical and lexical pronouns in the data, we created .cut files containing all the 137 French pronouns. Using the *freq* command in CLAN (MacWhinney, 2003), we first found the frequencies of each pronoun in each sample and then we used the *combo* command to go through each utterance one by one to check the contexts and to exclude the definite articles, which are homonymous to object pronouns.

We then calculated the total number of pronouns in relation to the total number of words. In order to compare the production of grammatical vs. lexical pronouns, we introduced the grammatical pronoun index (GPI), which is the proportion of grammatical pronouns in the total number of pronouns. The GPIs were calculated both for all pronouns found and for the pronouns remaining after excluding items found in fixed expressions. We also calculated proportions of pronoun subgroups within the lexical and grammatical groups, based on the classification in Table 3.1.

For the purpose of taking into account grammatical-lexical pronoun substitutions, we classified personal pronouns as correctly or incorrectly produced. An example of an incorrectly produced pronoun is found in (14).

(14) *Il va le manger*.

‘He is going to eat him.’

In this example the participant replaces the pronoun *la*, which refers to the grandmother in Little Red Riding Hood with *le*. Thus, the feminine direct object pronoun *la* is substituted with *le*, which has the wrong (masculine) gender.

We did the substitution count for personal pronouns only, as clitic subject pronouns are obligatory and therefore it is possible to predict the intended pronoun in an utterance when substitutions occur. We then compared correctly produced grammatical pronouns to correctly produced lexical ones. Finally, we made an analysis for each utterance where the production of a subject pronoun was inevitable (based on context). In each of these utterances we checked various combinations of clitic/non-clitic and finite/nonfinite verb production. We also looked at the data from the mildly affected participants qualitatively.

For each of the measurements mentioned above we obtained mean scores for the control group in each task. Participants with aphasia as a group, as well as individually, were compared to those means in each task separately. We used Fisher’s exact for statistical analysis. The significance threshold was set to $p<0.05$.

3.3 Results

3.3.1 Quantitative analysis

3.3.1.1. Pronouns in total number of words

Speakers with agrammatism produced significantly fewer pronouns (876 occurrences in 9476 words) compared to the non-injured control group (3530 occurrences in 15593 words, $p < 0.0001$ in all tasks. All speakers with agrammatism individually produced significantly fewer pronouns than the control group in each task, except for TH. Her performance reached significance only in the descriptive speech task (Table 3.2).

3.3.1.2. Grammatical pronoun indices

The group of speakers with agrammatism had a significantly lower GPI (mean = 0.55, SD = 0.33) in the autobiography task compared to the control group (mean = 0.89, SD = 0.05). In the other two tasks the GPI was not significantly lower for the group of speakers with agrammatism. When we looked at each speaker with agrammatism individually, it turned out that two participants with agrammatism out of six, PB and TH (the two most fluent ones), did not have significantly different GPIs compared to the control group in any of the three tasks (Table 3.3). The remaining four speakers with agrammatism showed a significant difference in the autobiographical task. In the narrative task the difference reached significance only for BR, while in the descriptive speech task, the difference was significant for three individuals with agrammatism. Apart from PB and TH, the GPI of one more patient (PC) failed to reach significance in the descriptive speech task (Table 3.3). The grammatical-lexical pronoun proportions are illustrated in Figure 3.1.

Table 3.2 Pronoun/word ratio for speakers with agrammatism and the control group in the three different connected speech tasks

Pron/Word	**Autobiography**	**Narrative**	**Descriptive**
BR	0.04****	0.02****	0.01****
MC	0.14****	0.05****	0.04****
PB	0.14**	0.11****	0.08****
PC	0.04****	0.04****	0.03****
SB	0.09****	0.04****	0.06****
TH	0.21	0.18	0.14*
Control	**0.18**	**0.18**	**0.17**

*$p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, **** $p \leq 0.0001$

When fixed expressions were excluded, one more figure reached significance: In the narrative task SB also showed significant impairment of grammatical pronoun production, compared to the control group. The other participants' performances remained the same (Table 3.4).

3.3.1.3. Grammatical and lexical pronoun subgroups

We also broke down the results for grammatical and lexical pronouns into smaller subgroups to see whether the statistical significance of the GPIs was caused by a certain subgroup (type-token ratios, Table 3.6) (see section 3.1.5 for the subgroups). However, we did not perform statistical tests on those numbers due to the small sample and the risk of increasing the possibility of a type 1 error (detecting significant findings when in reality they are not there). As it can be seen from the table, there are no consistent subgroups of grammatical pronouns that cause the dissociation. The interrogative and possessive subgroups in the lexical category are either zero or close to zero both in speakers with agrammatism and control speakers.

3.3.1.4. Subject pronoun substitutions

The ratio of correctly produced grammatical subject pronouns in the total number of subject pronouns was not significant for any of the individuals with agrammatism, except for BR in the autobiographical and narrative tasks, and MC in the autobiographical task. The ratio was not possible to obtain for BR in the descriptive task because the formula involved division by zero (Table 3.5).

a

b

c

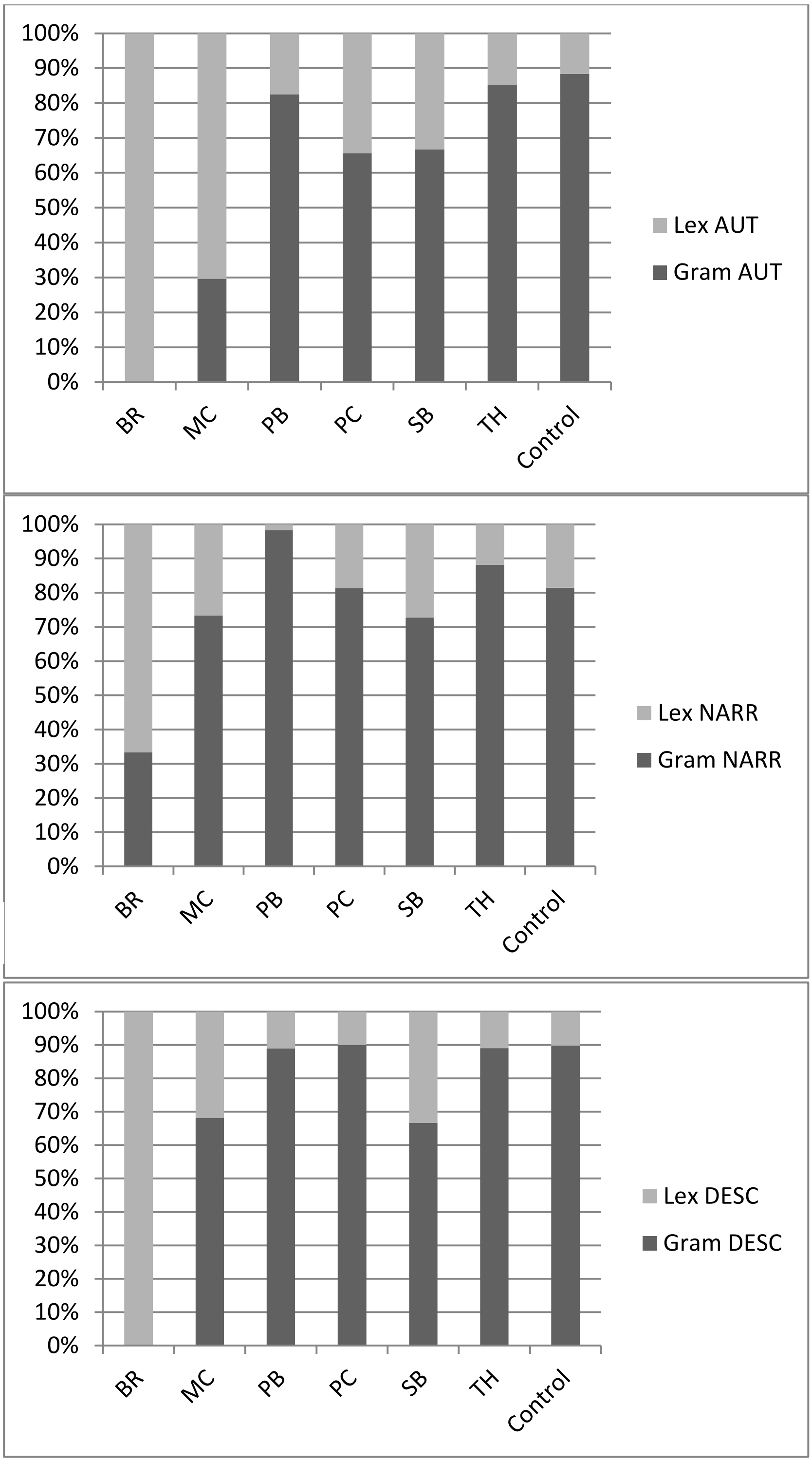

Figure 3.1 The proportions of grammatical and lexical pronouns for individual patients and the control group in a. autobiography (AUT) b. narrative speech (NARR) c. descriptive speech (DESC)

Table 3.3 Grammatical pronoun indices (GPI) for speakers with agrammatism and control group in the three different connected speech tasks

GPI	**Autobiography**	**Narrative**	**Descriptive**
BR	0****	0.33****	0***
MC	0.30****	0.73	0.68*
PB	0.61	0.98	0.74
PC	0.66**	0.81	0.90
SB	0.67**	0.73	0.67**
TH	0.85	0.88	0.89
Control	**0.89**	**094**	**0.90**

*$p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, **** $p \leq 0.0001$

Table 3.4 Grammatical pronoun indices (GPI) for speakers with agrammatism and control group in the three different connected speech tasks, excluding fixed expressions

GPI	**Autobiography**	**Narrative**	**Descriptive**
BR	0****	0.33*	0****
MC	0.35****	0.78	0.65**
PB	0.85	0.98	0.87
PC	0.68*	0.81	0.9
SB	0.71*	0.80*	0.73*
TH	0.90	0.88	0.87
Control	**0.88**	**0.95**	**0.89**

*$p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, **** $p \leq 0.0001$

3.3.2 Pronoun production in relation to verbs

In order to investigate whether the omission of clitic pronouns is related to the finite verb omission, we analyzed the relationship between verb and clitic vs. non-clitic pronoun production. In doing so, we were conservative when assessing the utterances where both a finite verb and a pronoun were required, as it is far from always clear how to reconstruct verbs and pronouns that seem to be omitted.

Table 3.5 The ratio of correctly produced grammatical subject pronouns (i.e. clitics) (cGRAM) in total number of correctly produced subject pronouns (cTOTAL)

cGRAM/cTOTAL	**Autobiography**	**Narrative**	**Descriptive**
BR	0***	0**	NA
MC	0.36***	1	0.88
PB	0.94	1	0.93
PC	1	1	1
SB	0.91	1	1
TH	0.88	0.90	0.93
Control	0.96	0.98	0.94

*$p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, **** $p \leq 0.0001$

We found the following constellations (n = 253):

(15) Clitic pronoun present, verb omitted

avant euh je beaucoup d'images

before euh I.clitic many pictures

'Before I many pictures.'

(16) Non-clitic pronoun present, verb omitted

peut-être moi site internet

maybe I.non-cl site internet

'Maybe I website.'

(17) Clitic pronoun present, nonfinite verb present

je partir un peu plus tôt

I leave-INF a bit more early

'I to leave a bit earlier.'

(18) Clitic pronoun omitted, finite verb present

alors regarde la vitrine

so looks the glasscase

'So looks at the glasscase.'

Table 3.6 Percentages of various subgroups of pronouns produced by the participants. The total pronouns at the bottom of the table indicate the raw number of pronouns produced by participants per task (A = autobiography, N = narrative, D = descriptive)

		BR			**MC**			**PB**			**PC**			**SB**			**TH**			**Control (mean)**		
	Pronoun types (%)	A	N	D	A	N	D	A	N	D	A	N	D	A	N	D	A	N	D	A	N	D
Grammatical	Personal	0	0	0	16	60	54	18	47	44	16	56	80	46	45	33	53	51	57	51	51	52
	Demonstrative	0	0	0	11	0	14	51	4	32	47	25	10	19	14	33	19	15	8	14	9	8
	Indefinite	0	0	0	1	0	0	4	0	1	3	0	0	0	0	0	0	2	0	9	2	2
	Relative	0	0	0	1	0	0	5	11	12	0	0	0	2	9	0	6	08	10	11	15	14
	Possessive	0	33	0	0	13	0	6	0	0	0	0	0	0	5	0	8	12	12	3	11	13
Lexical	Personal	81	67	0	15	0	9	1	0	1	0	0	0	4	0	0	6	3	3	3	1	2
	Demonstrative	0	0	0	49	20	13	10	1	5	22	13	10	29	23	33	8	3	1	7	3	5
	Indefinite	19	0	1	6	7	9	7	1	1	12	6	0	0	5	0	1	5	7	1	1	3
	Interrogative	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,1	0,1	0,3
	Possessive	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total pronouns (raw)		16	3	4	81	15	22	108	120	145	32	16	10	48	22	36	142	59	73	89	148	156

(19) Clitic pronoun present, finite verb present

il un vendeur lance un boomerang

he a salesman releases a boomerang

'He a salesman releases a boomerang.'

In (18) and (19) the intended verb form is derived from the context. It should have been *il regarde* ('he looks'). Phonologically, the form *regarde* could be present tense first, second or third person singular and also imperative.

In this group the vast majority of utterances were expressions like *je sais pas*, *je connais pas* ('I don't know'), *je pense* ('I think') and *je ne comprends pas* ('I don't understand'), some of which may be considered as fixed expressions (see the discussion below).

(20) Clitic pronoun present, non-clitic pronoun present, finite verb present

après moi je suis muet

afterwards I.strong I.clitic am mute

'Afterwards I am mute.'

Despite the fact that (20) contains both the obligatory and non-obligatory pronouns and the finite verb to make the sentence grammatical, the finite verb is in present tense, although it is referring to the past. The quantitative summary of these findings are shown in Table 3.7.

Table 3.7 Subject pronoun production or omission in relation to verb production or omission . The numbers indicate the occurrences of each combination (NCl = non-clitic, Cl = clitic, V = verb, F = finiteness)

NCl Cl V F	BR	MC	PB	PC	SB	TH
+ + + +	0	3	1	0	1	0
- + + +	0	12	63	0	20	84
- - + +	4	1	0	0	5	0
- - + -	20	3	0	0	24	0
- + - -	0	0	2	0	1	1
+ - + +	0	0	0	0	0	2
+ - + -	5	2	0	0	0	0
+ - - -	11	11	1	0	1	0
- + + -	0	0	0	0	1	7
- + - -	0	0	2	0	1	1

3.3.3 Qualitative analysis

As PB and TH were more fluent than the other participants with agrammatism, we decided to have a closer look at their speech samples. PB produced more grammatical pronouns in the narrative task than the control mean. What we found was that he used only two lexical pronouns in total. As table 5 illustrates, the extensive number of grammatical pronouns occurred at the cost of clitic and demonstrative pronouns. Further analysis showed that quite often he started the utterances with the expression *c'est* ('it is'), in which the demonstrative *c'* is classified as a grammatical pronoun. For example, in order to express that Cinderella and the prince got married, he used the utterance *C'est un mariage* ('It's a marriage'). The control speakers or the other speakers with agrammatism did not overuse *c'est.* PB also continuously used the clitic pronoun *il* ('he'), even when the referent was present in the sentence. Moreover, quite often it was ungrammatical substitution of *elle* ('she').

TH was the second outlier with a relatively fluent speech, based on WPM and MLU. We had a closer look at her sample to see whether there are signs of agrammatism or whether she was using adaptive strategies. The WPM and MLU measurements indicate that TH's agrammatic symptoms were milder and the verb omissions or inflectional errors were not as common. In one instance, for example, she omitted the finite verbs while producing the correct pronouns (21).

(21) *Elle lui ce qu'il va faire*

'She him [verb omitted] what he will do.'

TH often substituted pronouns with the wrong gender (*elle* with *il*). Also, she tended to use cleft constructions, which she did not always complete (22).

(22) *C'est une petite fille qui…*

'It's a little girl who…'

3.4 Discussion

3.4.1 Grammatical and lexical pronoun dissociation in agrammatism

3.4.1.1 Fewer grammatical pronouns in agrammatic speech

The findings are in line with previous research showing that speakers with agrammatism tend to omit pronouns (Nespoulous et al., 1990; Miceli & Mazzucchi, 1990; Månsson & Ahlsén, 2001; Stavrakaki & Kouvava, 2003; Martinez-Ferreiro, 2010; Brink, 2014). Previous findings include pronoun dissociations such as reflexive-direct object (Martinez-Ferreiro, 2010;

Sanchez-Alonso et al., 2011), subject-direct object (Nespoulous et al., 1988; Stavrakaki & Kouvava, 2003; Nerantzini et al., 2010), and direct-indirect object (Rossi, 2007). In our study we found that what we classified as grammatical pronouns based on Boye & Harder (2012) theory are more impaired than lexical pronouns in agrammatic aphasia. This classification also adds an explanation for why clitic pronouns are more sensitive to brain damage than non-clitic ones, as previously found (Nespoulous et al., 1990; Lonzi & Luzzatti, 1993; Stavrakaki & Kouvava, 2003; Chinellato, 2004, 2006; Rossi, 2007). Moreover, by looking into smaller subgroups of grammatical and lexical pronouns we show that it is not only a matter of non-clitic-clitic dissociation but also a wider range of pronouns that fall into the groups of grammatical as opposed to lexical pronouns.

Analysis of individual participants, however, shows that the grammatical-lexical pronoun dissociation does not occur in all the speakers with agrammatism in all three tasks. The only task in which all four severely impaired speakers with agrammatism produced fewer grammatical pronouns was the autobiography. It is not surprising that autobiography should stand out in this way. Autobiographical speech is considered the task with the least constraints, as no pictures are used to elicit speech and there is a larger variability in the linguistic forms the participants produce. The narrative task has more constraints than the autobiographical one because the participants were instructed to tell a well-known story with pictures to aid them. In this particular analysis the task with the most constraints is the descriptive one, where the participants are under pressure to tell a certain story based on a sequence of pictures. Using the same data, Sahraoui & Nespoulous (2012) have shown that as constraints are added to the task, the speakers with agrammatism produce fewer agrammatic constructions. A task variation effect has also been found in Dutch and German speakers with agrammatism (Hofstede & Kolk, 1994). A similar pattern emerges in terms of grammatical and lexical pronoun production in the current study.

3.4.1.2 Reliance on fixed expressions

The exclusion of fixed expressions did not change the picture drastically. Only SB's grammatical pronoun production in the narrative task became significant compared to the control speakers. It might therefore be concluded that at least when it comes to pronouns in the more constrained tasks, the individuals with agrammatism did not extensively rely on fixed expressions, except for SB. Note, however, that our identification of fixed expression was rather conservative. For speakers with agrammatism as well as non-injured speakers the inventory of fixed expressions may very well extend considerably beyond the group we identified. For instance, at least some cases of "epistemic stance" expressions like *je sais pas* ('I don't know') and *je pense* ('I think') may very well be fixed, as argued by Thompson (2002) (but see Boye & Harder, 2007 for discussion). If we had identified and excluded a larger group of fixed expressions, we might have found an even clearer dissociation between grammatical and lexical pronouns.

3.4.1.3 Substitutions

As for the substitutions, we expected that the less impaired individuals would rely more on substitutions rather than omissions of grammatical pronouns, as was the case in Sanchez-Alonso et al.'s (2011) study. Those substitutions could either be the production of grammatical pronouns with the wrong gender and number or simply by replacing them with the lexical counterpart. In order to adapt to the processing load, it is also possible that the participants with agrammatism substituted the pronouns with noun phrases (i.e. lexical items other than lexical pronouns), as described in Sanchez-Alonso et al. (2011). Our finding that all speakers with agrammatism produced a smaller number of pronouns in general compared to the control group is an indicator that substitution with a noun phrase could be a strategy they were using.

Despite the fact that the two moderately impaired participants did have substitutions, the results were not significant. This may be because the study of substitutions was only carried out on a subset of the pronouns, namely the subject pronoun, which have been shown to be relatively spared compared to object pronouns (Nespoulous et al., 1988; Stavrakaki & Kouvava, 2003; Nerantzini et al., 2010). We did not, however, want to include all the pronouns in this analysis because in many contexts it was difficult to reconstruct the intended utterance. Consequently, we only had a small number of pronouns to perform statistical analysis on. It is possible that the subset was too small and therefore the statistical power was lost. We therefore need larger samples and perhaps experimental data to look at substitutions.

3.4.1.4 Pronouns in relation to verbs

The dissociation we found might theoretically be an artefact of problems pertaining to verb production: since many grammatical pronouns are clitic and thus dependent on verbs, the group of grammatical pronouns might, considered as a whole, be affected by verb production problems (De Roo, 2002). In our pronoun-verb analysis we found all sorts of constellations of verbs and pronouns. In particular, the existence of utterances where the clitic pronoun is present and the verb is non-finite suggests that verb production problems need not affect the production of clitic pronouns in agrammatism. This means that the dissociation between grammatical and lexical pronouns in agrammatic speech is not likely to be an artefact, but rather may be attributed entirely to the grammar-lexicon distinction.

3.4.1.5. Boye & Harder's theory as an addition to processing theories

Boye & Harder's (2012) theory also supplements missing links in certain agrammatism processing theories. For example, Kolk (1995) argued that grammatical ("function") words are more demanding and therefore they are omitted in order to simplify the sentences. He does not, however, provide a motivation for why grammatical words would be more demanding. Boye & Harder's theory provides a possible motivation: grammatical items are omitted because they represent secondary information and are thus less important for communicative purposes. In other words, they can be dispensed with, in cases of resource limitations, because in contrast to lexical items they are not carriers of potentially main communicative points. Consider for instance (23):

(23) *I have hidden the money under the bed*.

In case of resource limitations you can omit the grammatical items and still convey the main point, as in (24).

(24) *I hide money under bed*.

In contrast, you cannot omit the lexical items, as in (25), and still make sense.

(25) *have -en the the*.

We have shown in this study that grammatical pronouns are particularly vulnerable to processing deficits. Future studies basing their predictions on the Boye & Harder (2012) theory may provide additional evidence about agrammatic impairment.

3.4.2 Adaptive strategies

Not all of our results fully support the grammatical-lexical pronoun dissociation in individuals with agrammatism. Interestingly, TH and PB, who did not have significant impairment of grammatical pronoun production in any of the tasks, are more mildly impaired compared to the other four (based on WPM and MLU). It could be the case that the grammatical pronoun deficit is too subtle to be detected in mild impairments, or that PB and TH are not speakers with prototypical agrammatism as their aphasia showed mixed patterns (Sahraoui & Nespoulous, 2012).

PB's patterns of pronoun production may be evidence for the development of a new, idiosyncratic grammar as a result of recovery, from the REF-model point of view (Mogensen, 2011, 2014). His language pattern still meets the criteria of agrammatism (Saffran, Berndt & Schwartz, 1989), but he is using adaptive strategies unique to him to cope with the deficit. For instance, he overuses *il* ('he'), even when the antecedent is *le cendrillon*, a noun with masculine grammatical gender but feminine natural gender and should be referred to with an *elle* ('she'). PB often begins utterances with *c'est* ('it is'). Most likely, these strategies (which may reflect unique patterns of connections between EFs) have developed as a result of his post-injury experiences (in the form of informal "training" or even training in rehabilitation program). In fact, the form *c'est + NOUN* is often used by speech therapists to "re-activate" or to "train" naming abilities. But his pre-traumatic experiences may also have contributed – by providing him with a pattern of neural connectivity favoring such processes.

SB's reliance on fixed expressions and TH's overuse of incomplete relative clauses could also be examples of adaptive strategies. Moreover, the varied dissociations of the grammatical and lexical pronoun subgroups among all of the participants (table 6) may also be taken as evidence for the development of distinct unique strategies. The variation found is a good indication of the fact that injury associated symptoms (in agrammatism and other cognitive impairments) are not simple reflections of loss of a specific process. Rather, the symptoms represent active and experience-dependent processes. Thus, if studies like the present one exclusively rely on the combined data from a group of individuals with agrammatism, important information may be lost.

One of the above presented examples may illustrate the involved mechanisms. Some of the EFs underlying the AS of grammar were lost to injury. Thus, in order to regain grammar, the existing EFs need to interact to create a new AS for grammar. This new AS will consist of some of the spared EF previously involved in the mediation of grammar as well as other EFs., Through experience and training PB's brain creates the new grammar AS (in the terminology of the later versions of the REF-model an Algorithmic Module (AM)). This experience dependent creation of a new AS is based on feedback based reorganization of the connectivity and interaction between individual EFs. However, the post-injury grammar AS is slightly different from the pre-injury one. For instance, in this grammar the pronoun *il* carries information about grammatical gender but it is not used to refer to natural gender. Thus, *le cendrillon* is referred to as *il* in this particular new grammar. Such a situation – that is, such an organization of the grammar associated AS – occurs because:

a) that type of information processing can be achieved by combination of the EFs spared by injury,

b) when that AS is activated (and the described type of grammar produced) the feedback to the patient is positive since the produced grammar is understandable and serves communicative purposes.

The current data are a starting point for investigating the patterns of language recovery after stroke in relation to the REF-model. However, it is difficult to capture the whole picture with these data. Longitudinal data are necessary to further explore the REF-model in terms of post-injury recovery and to construct the steps each individual with agrammatism takes to build a new grammar.

3.5 Conclusion

This study provides a new view on pronoun processing impairment in agrammatic aphasia. Based on Boye & Harder's (2012) theory of the distinction between lexical and grammatical elements, we show that in agrammatism grammatical pronoun production is more affected than lexical pronoun production. This generalization covers the findings, reported also in earlier studies, that clitic personal pronouns (grammatical) are more impaired than the non-clitic personal pronouns (lexical) (Nespoulous et al., 1990; Lonzi & Luzzatti, 1993; Stavrakaki & Kouvava, 2003; Chinellato, 2004, 2006; Rossi, 2007). The data from individual speakers with agrammatism also support the REF-model (Mogensen, 2011, 2014) and the possibility of reorganization in the brain as a result of brain injury.

Future research involving pronoun eliciting experiments may include larger groups of individuals with agrammatism to investigate predictions based on Boye & Harder’s (2012) theory. Moreover, it would be interesting to see what the results would be for other languages, as so far this theory has been tested only on French and Danish speakers with agrammatism (Brink, 2014). More data are necessary to investigate the new, often impoverished and imperfect grammars which the individuals with agrammatism may develop (as well as to address the neural substrate of these new processes) in order to further test the predictions of the REF-model.

CHAPTER 4

The meeting point: Where language production and working memory share resources

4.1 Introduction

Working memory (WM) is traditionally defined as a system for temporarily storing and manipulating information (Cowan, 1999). It is described as having a storage component, which can store a limited amount of information for a limited amount of time, and a processing component, which is responsible for manipulating the given information (Daneman & Carpenter, 1980).

The interaction between working memory (WM) and language has long been discussed in cognitive research. In such studies, however, often the terms WM and short-term memory (STM) are used interchangeably. Unlike WM, STM does not have a processing component and it serves as a passive storage to perform tasks like digit forward span. WM, on the other hand, is necessary for performing complex span tasks (Daneman & Carpenter, 1980). In complex span tasks apart from remembering the items to be recalled, participants are simultaneously engaged in another activity, such as reading. In language studies it is more reasonable to use WM measurements, as complex span tasks are a better predictor for reading comprehension (Daneman & Merikle, 1996).

While both STM and WM measures predict language comprehension, complex span scores have been shown to have a stronger correlation with reading comprehension scores (Daneman & Merikle, 1996). Digit span and complex span scores have been in turn shown to be correlated both with each other (Daneman & Merikle, 1996) and executive functioning scores (Miyake, Friedman, Rettinger, Shah & Hegarty, 2001), suggesting that they are all components of the same system.

Unlike language comprehension, studies addressing the role of STM or WM in language production are scarce, although there is some evidence about the relationship between language production and WM capacity (Acheson & MacDonald, 2009; Hartsuiker & Barkhuysen, 2007). In a subject-verb agreement production study Hartsuiker & Barkhuysen (2007) have shown that individuals with lower WM span are having more difficulties in planning the correct subject-verb agreement. Thus, language production indeed requires WM resources and the interaction between WM and language production should not be neglected.

The interaction between WM and language production can be understood by examining language production models (e.g. Bock & Levelt, 2002), which assume that the utterances to be articulated need to be planned in advance: from the point of coming up with the idea to the moment of articulation the utterance is processed at certain stages. For instance, in the Bock & Levelt (2002) model at the message level the concept is being formulated. In the functional level appropriate words are selected (lexical selection) and function is assigned. Next, words are positioned in the correct order and grammatical functions are selected (positional level). The final level prior to articulation is the phonological encoding, where appropriate phonemes are assigned and phonological rules are applied. Additionally, incremental models suggest that while articulating, the speaker is at different levels of planning for each individual word of the sentence (Ferreira & Swets, 2002). Therefore, it is reasonable to assume that there is some kind of a system that holds all the elements of the utterance at different levels of planning, while the speaker is articulating.

It is also possible that at each level of language planning there is a separate temporary system to keep the elements of that level activated. MacDonald (2016) argued that utterance planning is a demanding task and requires WM involvement. Acheson & MacDonald (2009) reviewed a vast amount of literature, showing parallels between language production research and WM research and arguing that language production plays an important role in maintaining short-term information, especially at the phonological encoding level.

While the role of WM in language production may be undeniable, it is still difficult to predict at which level of language planning WM is the most involved and whether different types of WM play a different role in language planning. Baddeley's (1986) original WM model involves a phonological component: a phonological loop. Early studies failed to show that the phonological loop component of Baddeley's (1986) WM model serves as a buffer for the phonological encoding level of Garrett's (1975) speech production model (Klapp, Greim & Marshburn, 1981). Instead, there is some evidence that the central executive (the attentional component) of the WM model is important for language production (Daneman & Green, 1986). However, the central executive is considered domain-general (Conway, Kane & Bunting, 2005) and therefore it may play an important role both in language production and WM task performance, as well as other cognitive functions.

Additionally, language comprehension and WM studies of injured population have shown that the role of WM in comprehension is not purely phonological (Friedmann & Gvion, 2003; Wright, Gravier, Love & Shapiro, 2007). Friedmann & Gvion (2003) have distinguished between phonological WM, which stores words at phonological level, and syntactic WM, which is responsible for processing syntactically complex sentences. Similarly, Wright et al. (2007) have shown that there are separate WM types involved in different types of linguistic information processing. In terms of language production, this could be interpreted as phonological WM taking part in phonological encoding, while the syntactic WM is involved at the positional level.

The above-mentioned studies are in favour of multiple resource theory (Caplan & Waters, 1999), according to which there are multiple types of WM (e.g. syntactic and semantic) involved in language comprehension. The single resource theory (Just & Carpenter, 1992) is opposed to the multiple resource theory and suggests a single computational system for all types of linguistic processing. Both views, however, have been developed based on sentence comprehension studies. The small number of empirical research on language production and WM makes it difficult to transfer these views to language production.

In theory, WM could be involved at any level of language production planning. If there is a different type of WM involved for each level of planning, certain WM tasks would interact with language performance, while others would not. For instance, in a production task where after each sentence the participant has to memorize a word in order to recall them after a certain sequence of sentences, one might assume both the phonological and the lexical storages get involved, while in non-word repetition only phonological storage is required.

The interaction between WM and language is not a one-way process. While WM may have a role in language processing, language in turn facilitates WM task performance (Conrad & Hull, 1964). Indeed, studies have shown that it is easier to memorize connected words than random words or even non-words (Hulme, Maughan & Brown, 1991). Therefore, it is possible to claim that language has a somewhat facilitatory effect on WM performance. In fact, WM in turn facilitates language production. A study with a WM preload condition showed that reaction times decreased once the production preload was added (Power, 1985).

These facilitatory effects raise the question whether language and WM are interacting separate systems or one complex system that cognitive neuroscientists are artificially trying to tear apart. In this paper we suggest a new neurocognitive model that may explain the degree of interaction between WM and language. As a building block of the model, we investigate at which levels of language planning WM is involved. We base our assumptions about language on a usage-based theory of grammatical theory (Boye & Harder, 2012), which will be presented shortly after we discuss the neurocognitive model. We test our assumptions in a language production and WM behavioural experiment.

4.1.1 The REF-model

The reorganization of elementary functions (REF) model (Mogensen, 2011, 2014) suggests not only how cognitive functions are organized in the healthy brain but also how they recover after an injury. For the purpose of this paper we will focus on the former.

The model consists of three levels. The lowest level comprises elementary functions (EFs). The EFs are truly localized in the sense that the neural substrate of an EF is restricted to a specific subdivision of a brain structure (e.g. neocortical area). EFs are not traditionally defined cognitive functions and may be best described in mathematical terms. The top level consists of the surface phenomena – things that can be observed at a behavioural level or experienced as mental phenomena. The interaction of numerous EFs creates algorithmic modules (AMs) through experience and learning, which in turn interact to create algorithmic strategies (ASs) (Figure 4.1). A single AS serves as a basis for a surface phenomenon, while AMs on their own cannot manifest as surface phenomena. It is important to mention that various EFs can be part of different AMs. When brain injury occurs, certain EFs are irreversibly lost. Therefore, the existing EFs reorganize through experience (potentially including therapeutic training) to create new ASs, which are able to be the basis for surface phenomena apparently similar to the ones lost to injury. It is, however, important to notice that neither the new ASs nor the 'recovered' surface phenomena are identical to what was present before the injury.

To be more specific about WM and language, we suggest that certain EFs interact to create AMs for different language components (e.g. grammar, lexicon, phonology, etc.). The interaction of those AMs creates an AS for sentence production. The activation of that AS results in the surface phenomenon of sentence production. The AS of a given WM manifestation may also have its interacting AMs. Some of the interacting AMs may be shared with the sentence production AS and the others may be unique. In this paper we observe where exactly this overlap happens and to what extent WM and sentence production do not interact.

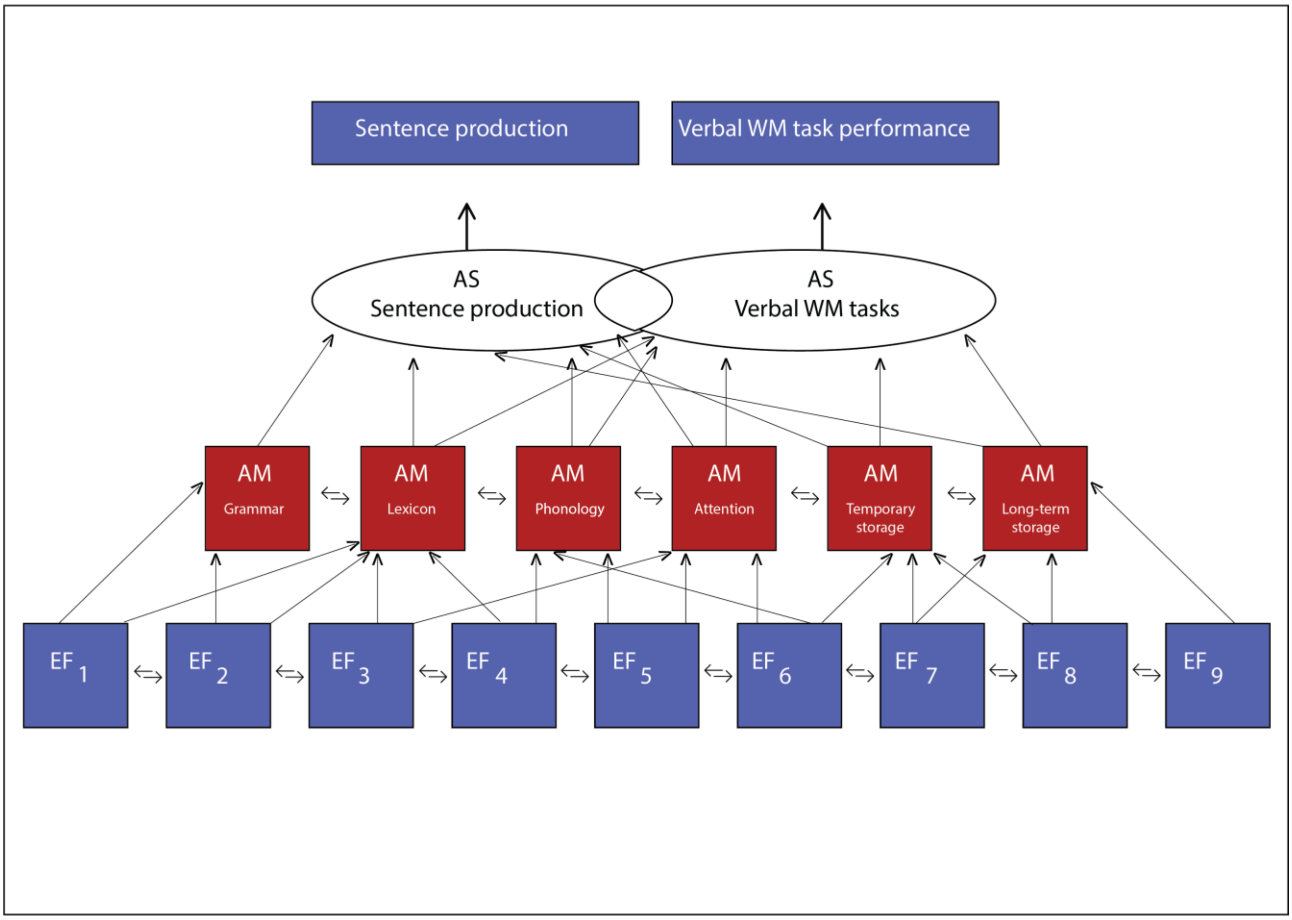

Figure 4.1 A simplified version of the potential relationship between the mechanisms of sentence production and verbal aspects of WM in the context of the REF-model . The EFs (elementary functions) interact to create algorithmic modules (AMs), the interaction of which results in algorithmic strategies (AS). Each AS is a program for a surface phenomenon.

4.1.2 A Usage-based theory of grammatical status

A usage-based theory of grammatical status (Boye & Harder, 2012) suggests that grammatical items represent secondary (or background) information, cannot convey the main point of the utterance, and cannot be focalized. Lexical items, on the contrary, potentially represent primary (foreground) information, can convey the main point of the utterance, and can be focalized by means of clefting or focalizing items. In (1), for example, the indefinite article *a* would be a grammatical item, while in (2) the numeral *one* would be a lexical item.

(1) a red ball

(2) one red ball

According to the above-mentioned theory, grammatical items are dependent on lexical items and cannot be uttered without a lexical host. In contrast, lexical items can in some cases be uttered in isolation from other items, as in *car! fire!* To integrate the linguistic theory with the REF-model, we assume that grammar is an AM and thus cannot in itself result in a surface phenomenon. Therefore, it has to interact with some other AMs (i.e. lexicon) to result in an AS, which in turn can serve as a basis for sentence production. The lexicon AM, however, can result in an independent AS and therefore serve as a basis for lexical production.

4.1.3 Aims and hypotheses

The aim of this paper is to investigate the relationship between WM and language production from the perspective of the REF-model (Mogensen, 2011, 2014) and the Boye & Harder (2012) theory, respectively. To make sure we are investigating an interaction between WM and language production, the WM load is gradually added during the language production task.

The question we address is how WM and language production overlap, if at all. There are three hypotheses developed from this question:

1. If there is a phonological overlap, we expect lower WM scores when the participants have to produce longer utterances, and a trade-off between WM scores and reaction times (RTs).

2. If there is a lexical overlap, we expect lower WM scores in the lexical condition compared to the grammatical condition, and RT-WM tradeoff in the lexical condition but not in the grammatical one.

3. If there is a grammatical overlap, we expect lower WM scores in the grammatical condition than in the lexical one, and RT-WM tradeoff in the grammatical condition but not

in the lexical one.

Of course it is possible that WM and language production overlap in more than one of these levels. In that case we expect a general correlation between WM and RT measurements, independent of the condition. But such a general finding will make it difficult to draw conclusions about WM and language production being separate ASs.

The secondary question is whether WM is one complex system (single resource theory; Just & Carpenter, 1992) or an umbrella term for multiple more simple systems (multiple resource theory; Caplan & Waters, 1999). Additionally, we will also investigate the role of STM in this whole language production system by independently measuring digit span.

4.2 Method

4.2.1 Participants

Twenty-one right handed Danish native speakers with no history of brain injury participated in the study (9 male, aged 20 – 55). They were recruited through social media and advertisements through friends and relatives.

4.2.2 Materials

For the digit span task, each digit was recorded by a male Danish speaker. Then each single digit was combined with others to form strings with a length of two to nine. We created two different strings of each length. The digit span task was programmed in PsychoPy (Peirce, 2007).

For the production task we used the paradigm developed by Michel Lange, Messerschmidt & Boye (in progress). The paradigm has two conditions: grammatical (1) and lexical (2). We contrasted lexical numerals (like English *one*) (1) with grammatical indefinite articles (like English *a/an*) (2). In both conditions the expected response was phonologically similar and only differed in terms of stress and content. For the grammatical condition we contrasted colour (1) and for the lexical condition we contrasted the number (2).

(1) *Jeg har et rødt brev. Hvad har du?*

‘I have a red letter. What do you have?’

Expected response: *et blåt brev.*

‘A blue letter.’

(2) *Jeg har to røde breve. Hvor mange har du?*

‘I have two red letters. How many do you have?’

Expected response: *et rødt brev.*

'One red letter.'

For this task 16 frequent concrete Danish nouns were chosen (eight neuter gender and eight common gender, eight mono- and eight bisyllabic) and line drawings in four colours were made. The stimulus sentences and the questions were recorded with a female voice of a Danish speaker. After the question a picture appeared on the screen and the participant had to answer the question accordingly. The responses were recorded and response times (RTs) were measured (counting from the moment of stimulus presentation to the articulation onset).

For the WM task, we used the production version of the modified listening span task (Ivanova & Hallowell, 2014). In the study of Ivanova & Hallowell (2014) participants were asked to remember the concrete nouns presented to them between each item of the sentence-picture matching task. After a couple of sentences, they saw a screen with multiple pictures and were asked to recognize the nouns presented to them previously.

We translated the English nouns into Danish. However, we could not include all of them in the experiment as some of the English monosyllabic nouns translate into bisyllabic ones in Danish. For that reason we came up with additional monosyllabic concrete nouns in Danish. The frequency of the nouns was checked using a 56 m word text corpus (KorpusDk) and it ranged from 143 to 24719 occurrences in a million. The full list of the nouns can be found in Appendix D. To avoid phonological similarity effect (Allen & Hulme, 2006), we made sure that the first phoneme of the WM task noun was different from the noun in the production task. We also ensured the gender of the WM noun was matched with the gender of the noun in the production task. The nouns in the WM task were recorded with voice of a male Danish native speaker. Two independent Danish native speakers were asked to hear all the nouns and write down what they heard. The misheard nouns were excluded from the study. Like the digit span task, the production and the WM tasks were programmed and presented in PsychoPy (Peirce, 2007). An example of the paradigm can be seen in Figure 4.2.

4.2.3 Procedure

The experiment started with the digit span task. The participant heard a string of digits and had to repeat the string immediately. If correctly repeated, they heard a string that was longer by one digit. If a mistake was made, they heard an additional string with the same length. If the second string was recalled correctly, they heard a string with one additional digit. If they made an error in the second string with the same length, the digit span task ended and the maximum number of correctly recalled strings was noted down as the participant's digit span.

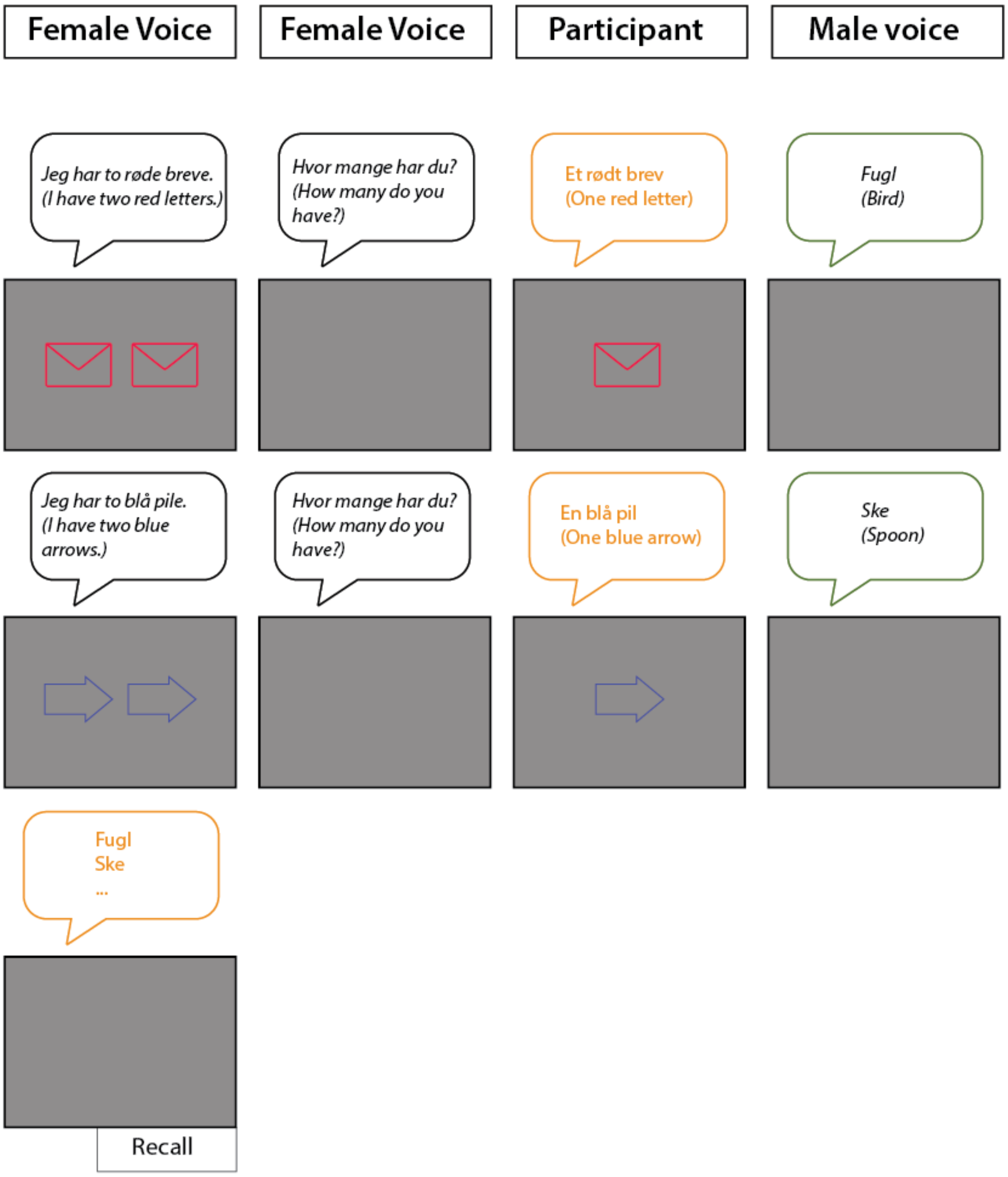

Figure 4.2 A sample of the experimental paradigm. The participant hears the sentence and sees the corresponding picture, which is followed by the same voice asking a question. The English sentences in brackets are given for translation purposes and were not present in the actual experiment. Afterwards a new picture appears and the participant has to respond accordingly. Subsequently the participant hears a word to memorize and the same procedure repeats. After 4, 5, 6 and 7 trials a recall screen appears.

After the digit span task, the production-working memory experiment began. First, the participants were presented with the nouns in the production task with their names written under them. Then they saw the pictures without the names and they had to name them. Afterwards, they had a practice session with the production task. Then they were introduced to the WM load task and had another practice session with the load added. After the production task and load practice session the real experiment began.

In each trial the participant first completed the production task and then heard a word for the WM load task. After four, five, six and seven trials the participants were asked to recall the nouns they heard. The lexical and grammatical, mono- and bisyllabic conditions were presented in blocks and thus there were four blocks per participant (2x2 design). The blocks were counterbalanced across participants.

4.2.4 Scoring

RTs and accuracy were measured for the production task and WM span was measured for the memory task. The RTs were manually extracted from audio files using *Praat* (Boersma, 2002) by an assessor naïve to the aims of the experiment. Only RTs to correctly produced sentences were included in the RT analysis (93% of all the data points). The sentences were scored as correct if all the components (the determiner or the numeral, the adjective and the noun) were present and the agreement was correct. As for the WM task, in order to be counted as correct, the nouns had to be recalled in the order they were presented. The number of correctly recalled items was summed up for each of the four blocks.

4.2.5 Data analysis

We used linear mixed models and generalized linear mixed models to test our hypotheses. For the three outcome variables (RT, accuracy and WM score) we used three models: (1) RT as an outcome variable, syllables (mono- and bisyllabic), condition (grammatical and lexical) and load (4, 5, 6 and 7) as fixed effects and item and participant as random effects (linear mixed model). There was one extreme value on the residual plot. That value was removed and the model was run again. (2) Accuracy as an outcome variable, syllables, condition, and load as fixed effect variables and item and participant as random effect variables (generalized linear mixed model, binomial family), (3) WM score as an outcome variable, syllables and condition as fixed effects and participant and item as random effects (linear mixed model). We also tested for correlation between the dependent variables (digit span, RT, accuracy and WM score), for which we calculated mean RTs, WM scores and accuracies for each participant.

All the statistical analysis was carried out in R (R Core Team, 2012). The mixed models were constructed using the lme4 package (Bates, Maechler & Bolker, 2012).

4.3 Results

Summary of descriptive statistics is given in Table 4.1.

Table 4.1 RTs, accuracy and WM scores for all conditions

	RT ± SE (ms)	**Accuracy ± SE (%)**	**WM score ± SE**
Grammatical			
Monosyllabic	965 ± 16	90 ± 1.3	16.6 ± 0.8
Bisyllabic	1010 ± 19	90 ± 1.4	18.2 ± 0.9
Lexical			
Monosyllabic	857 ± 15	96 ± 3.5	17.6 ± 0.9
Bisyllabic	1037 ± 21	97 ± 0.8	19.4 ± 0.6

RT = mean reaction time, SE = standard error, WM = working memory

Overall, the number of syllables affected RTs. Responses containing a bisyllabic noun were produced slower than responses with monosyllabic nouns (b = 61, t (16) = 3.1, p = 0.007). RTs were affected by load, too. Increasing load by one unit resulted in faster RTs (b = -26, t (1693) = -3.6, p = 0.0003). Grammatical and lexical conditions, however, had no significant effect on RTs (b = 5.7, t (1700) = 0.3, p = 0.71) (Figure 4.3a.).

Unlike RTs, accuracy was affected by condition. In the lexical condition participants were likely to be more accurate. For every change in condition from grammatical to lexical accuracy log odds increased by 1.6 ± 0.25 (standard errors) (z = 6.2, p < 0.001). Neither the number of syllables (b = 0.06, z = 0.25, p = 0.8), nor load had an effect on accuracy (b = -0.09, z = -0.9, p = 0.36) (Figure 3b.).

Condition did not affect WM scores (b = 0.5, t (37) = 0.98, p = 0.33). Interestingly, bisyllabic word production slightly improved WM scores compared to monosyllabic word production (b = 1.7, t (37) = 3.1, p = 0.004) (Figure 4.3c).

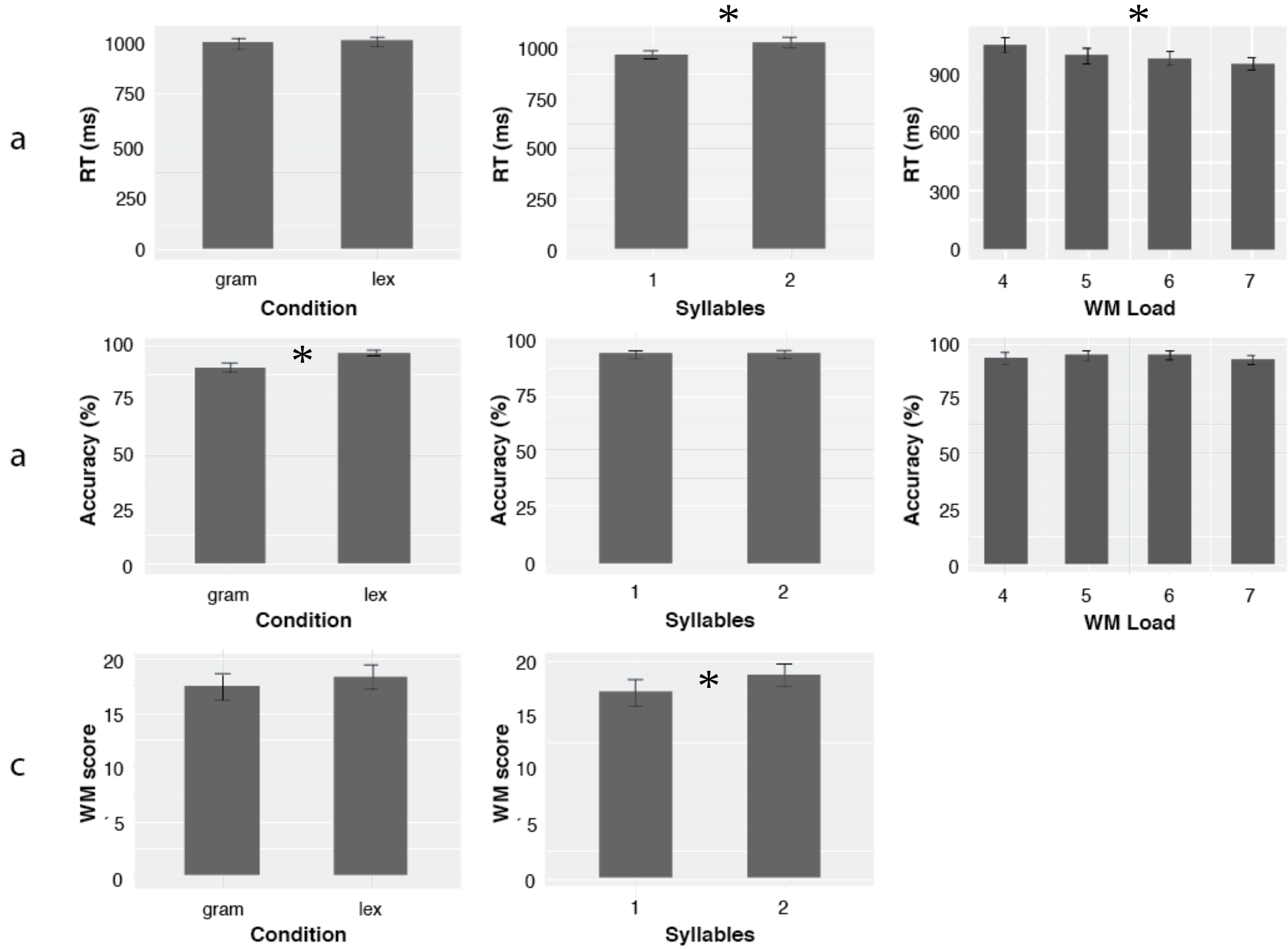

Figure 4.3 The effect of condition (gram = grammatical, lex = lexical), syllables (1 = monosyllabic, 2 = bisyllabic) and working memory (WM) load (4, 5, 6 and 7) on reaction times (RT) (a), accuracy (b) and the effect of condition and syllables on working memory (WM) score. The asterisk indicates a significant difference.

We also classified the production task errors into five different groups: agreement errors (when the gender of the determiner, the numeral or the adjective was incongruent to the noun), disfluencies, insertions (when the participants inserted one or more words in the target utterance), omissions (determiner or numeral omissions), substitutions (when the noun or the adjective were substituted with another noun or adjective). As can be seen in Table 4.2, in the grammatical condition the vast majority of errors are determiner omissions, which is not the case in lexical condition (Fisher's exact $p < 0.0001$).

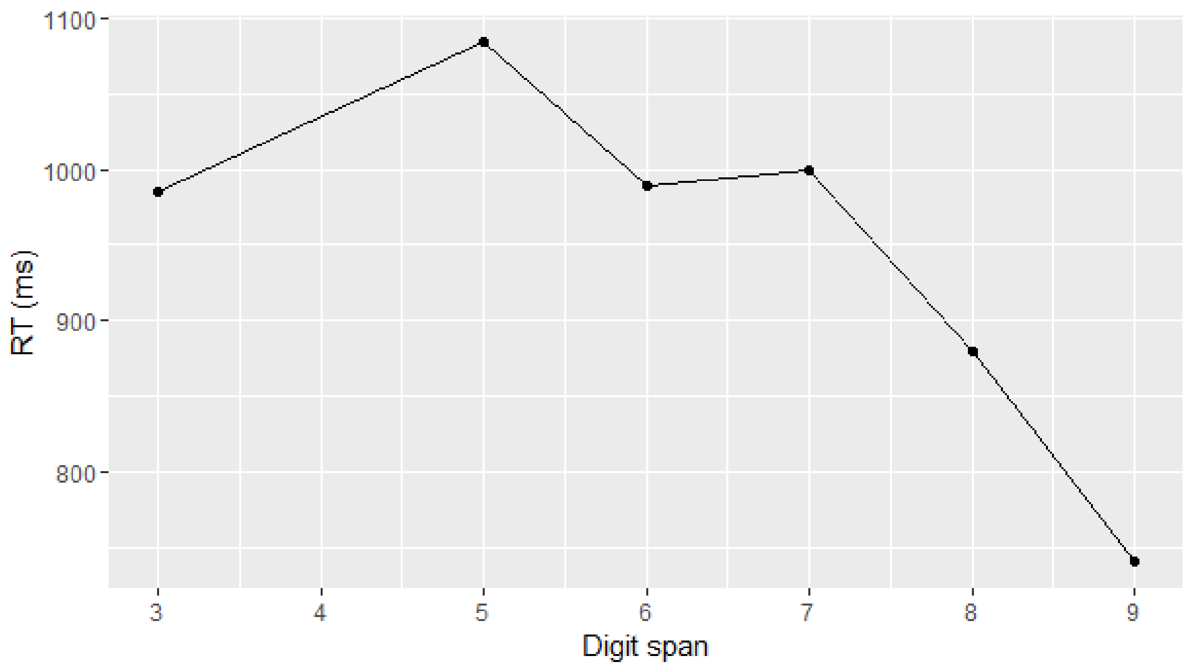

Figure 4.4 The mean RTs for each digit span. There is a tendency of negative correlation between RTs and digit span, showing that individuals with smaller spans tend to respond slower.

Table 4.2 Error types in percentages in grammatical (Gram) and lexical (Lex) conditions.

Error (%)	Agreement	Disfluencies	Insertions	Omissions	Substitutions
Gram (*n* = 91)	1.1	12.1	1.1	80.2	5.5
Lex (*n* = 30)	6.7	60	3.3	3.2	6.6

We did not detect a correlation between RT and accuracy (Pearson's *r* = -0.102, *t* (19) = -0.45, *p* = 0.66). Interestingly, there was no significant correlation between digit span and WM scores (*r* = -0.03, *t* (19) = -0.13, *p* = 0.89), or between WM and RT (*r* = -0.03, *t* (19) = -0.15, *p* = 0.89). There was a negative tendency between digit span and RT, which failed to reach significance (*r* = -0.34, *t* (19) = -1.67, *p* = 0.11) (Figure 4.4). There was, however, a significant correlation between accuracy and WM measures (*r* = 0.47, *t* (19) = 2.3, *p* = 0.03).

4.4 Discussion

The results are in line with previous findings that word length affects RTs (e.g. Meyer, Roelofs & Levelt, 2003). Indeed, it takes longer to plan bisyllabic words compared to monosyllabic ones. Considered that WM has a limited capacity, it is surprising, however, to see a positive effect of number of syllables on WM performance. One could argue that if WM has a role in phonological level of language planning, the WM scores should have decreased in the bisyllabic condition rather than improved, as the planning of longer words would use more storage space and therefore limit the number of words that a participant could memorize. If the load was not enough to reach the limits of WM, we would at least not find a syllable effect on WM scores. Similarly, the responses became faster when load increased.

Such a facilitation effect was described by Power (1985). In his experiment participants had lower RTs in producing sentences when there was a digit pre-load compared to the non-load condition. Power (1985) explained this finding by the participants' "desire of not forgetting" the digits and therefore responding as fast as possible to the sentence production task. Our experimental design and therefore findings are not exactly the same as those of Power (1985). Instead of a pre-load, we added the load during the task and as a result WM performance was improved in the condition where RTs were slower (i.e. bisyllabic). Similarly to Power's (1985) findings, RTs were faster when the load became larger. We cannot explain this by the desire of memorizing, as we did not have a completely non-load condition. Moreover, the load was added gradually but the participants knew in advance that the load was going to increase. They did not know, however, that the 7 word load was going to be followed by 4. Therefore, the desire of memorizing the words should have stayed the same once maximum load was reached, which did not happen.

The fact that in the bisyllabic condition WM was better and RT was slower indicates that indeed there is a shared system between language production and WM, which cannot be explained by the traditional storage-processing components proposed by Daneman and Carpenter (1980). While additional phonological load slowed down language processing, it facilitated WM. It is possible that the activation of the additional syllable activated more storage space for the WM task and therefore it became available to accommodate more information in the temporary storage.

The REF-model also provides an explanation for the facilitation phenomenon. It is possible that while performing the language production and WM task, the interaction of several AMs, such as phonological, lexical and temporary storage, form a task-specific AS, which is separate from the sentence production AS and therefore has its own capacity for maintaining the required words for the WM task. In the meantime, the sentence production continues with the "old" sentence production AS, which has limited phonological capacity and therefore the production slows down, when the speaker plans longer words to produce.

The finding that the grammatical and lexical condition does not have an effect on either RT or WM indicates that at the functional and positional levels there is no interaction between language production and WM. In the grammatical condition, however, the participants tended to be less accurate. This indicates that the grammatical task is more difficult than the lexical one (in line with the theoretical assumption that grammatical items have an extra dependency), but the difficulty of the task does not require more WM capacity, as the increasing WM load had no effect on accuracy. This is contradictory to what Hartsuiker and Barkhuysen (2007) have shown. It is possible that the production task in the current experiment was too easy and the added WM load did not reach the limit of the participants' capacity. Also, the WM task consisted of phonological and lexical information and did not have a grammatical component at all. It would be interesting to run a similar experiment, adding grammatical manipulation to the WM task. It is also possible that the central executive component of WM plays a role in grammatical planning. As grammar according to Boye & Harder (2012) represents background information, less attention may be used during this type of production and therefore more errors occur.

The error analysis showed that the vast majority of the errors in the grammatical condition were article omissions, which is in line with Boye & Harder's assumption (2012) that grammatical items are less important and thus can be omitted. It is possible that the participants omitted the articles to open extra space for the WM load. Thus, the RTs stayed the same but the accuracy dropped. In this context the target lexical items are the essential part of the utterance and therefore they cannot be dropped, while grammatical items are easily omitted, as they carry secondary information. As such errors happened only in the grammatical condition, we assume that WM and grammatical retrieval share common resources more than WM and lexical retrieval.

The lack of correlation between WM scores and digit span was surprising because traditionally digit span is used for measuring the passive, storage component of WM, also known as STM. While WM and STM are not the same thing, they share certain features and are to different extents correlated to reading comprehension (Daneman & Merikle, 1996). At the same time, digit span showed a tendency of being correlated with RTs. The lack of significance may be due to a small sample size. Thus, a future study with a larger sample may be necessary to confirm this relationship. There was, however, surprisingly a significant positive correlation between accuracy and WM measures, which indicates that for the WM and the language production task the same resource was not being used at the cost of the other. Such a relationship between accuracy and WM and a potential relationship between digit span and RT may be an indicator of generally better cognitive abilities.

Failure to detect a correlation between WM and production RTs may be because different type of WM is engaged in language production than in comprehension and therefore the findings for comprehension studies are not generalizable on production. Alternatively, it is possible that the current task was not challenging enough for the participants to detect either a trade-off between WM and RT or grammatical and lexical task effects. Future research with more demanding language production tasks and a comparison between production and comprehension complex span scores will shed light on this issue.

4.4.1 Conclusion

Our findings show that WM is involved at the phonological encoding level of language production. Moreover, adding WM load facilitates the language production task, which can be explained by the formation of a task-specific AS. We did not, however, detect a tradeoff between WM measures and RTs, which suggest that the interaction between WM and language production is not notable. STM, on the other hand, could be a good predictor for language production speed. More studies are necessary to examine this question much deeper. We have also shown that "extra grammar" is more difficult than "extra lexicon". Future research may focus on whether WM has a role in planning grammar and lexicon.

CHAPTER 5

Grammar - lexicon distinction in a TMS study

5.1 Introduction

In order to produce a grammatically correct utterance it is required that all the elements of the utterance are in place. It is generally agreed that among other areas, frontal and temporal cortices are involved in language processing (Price, 2010). But the role of Broca's area, located on the left inferior frontal gyrus (LIFG) and consisting of Brodmann's area (BA) 44 and 45 (or pars opercularis and triangularis respectively), is still of high importance (Ardila, Bernal & Rosselli, 2016). Recent neuroimaging studies have shown that the LIFG plays a more complex role in language processing than only speech production and that it is not limited to BA 44 and 45 (Hagoort, 2005). BA 44 and BA 45, for instance, have been shown to be activated in syntactic comprehension (Dapretto & Bookheimer, 1998; Caplan, Alpert & Waters, 1998; Friederici, 2009, see Cappa, 2012 for a review), whereas BA 47 (pars orbitalis, anterior part of LIFG) is mainly activated for semantic processing (Dapretto & Bookheimer, 1998; Hagoort, Hald, Bastiaansen & Petersson, 2004; see Price, 2010; 2012 for reviews).

The choice of a specific task is crucial for examining the role of a certain cortical area in language processing (Cappa, 2012). For instance, in a sentence production task, BA 45 is more activated than BA 44, compared to a word production task (Haller, Radue, Erb, Grodd & Kircher, 2005). In addition, BA 44 activation has been specifically shown in a sentence comprehension task with low semantic predictability (Obleser & Kotz, 2009), while BA 47 was selectively activated in sentences with high predictability (Obleser, Wise, Dresner & Scott, 2007). Also, Grodzinsky (2000) argues that Broca's area (BA 44 and 45) is mainly involved in the 'movement' function of grammar and grammatical items are stored elsewhere in the brain.

While neuroimaging techniques show which cortical areas are activated in language production, speech production models suggest the stages of the processing of the elements in the utterance (Bock & Levelt, 1994; Levelt, 1989; Garrett, 1975). At the message level a concept is being formulated, after which the correct words (lexicalization) and their grammatical features (syntactic planning) are chosen. It is then followed by the phonological level and articulation, where the correct phonemes are selected and articulation is planned. Based on a meta-analysis of neuroimaging and ERP studies, Indefrey & Levelt (2004) provided a detailed speech production model in which they proposed a time course for the events and brain areas involved. They argue that the lexical concept planning happens at around 175 ms post-stimulus onset, whereas the lemma selection is complete at around 250 ms, followed by the phonological planning. In their model, LIFG gets involved only after lemma selection at the level of syllabification. This model is, however, based solely on single word production in naming and word generation tasks. Thus, it does not cover the full processes of language production.

In language studies, transcranial magnetic stimulation (TMS) is used to generate virtual lesions to show a causal relationship between a cortical area and a language function (Devlin & Watkins, 2008). Through a coil placed on the scalp, a magnetic field is induced over the scalp by means of rapidly changing current. This magnetic field alters the underlying cortical activity. As a result, reaction times (RTs) slow down and the responses become less accurate (Pascual-Leone, Bartres-Faz & Keenan, 1999; Walsh & Rushworth, 1999). TMS, however, can also have a facilitatory effect on RTs both in high and low frequencies (Mottaghy, Hungs, Brügmann, Sparing, Boroojerdi, Foltys, Huber & Töpper, 1999; Andoh, Artiges, Pallier, Rivière, Mangin, Cachia, Plaze, Paillère-Martinot, & Martinot, 2006; Sakai, Noguchi, Takeuchi & Watanabe, 2002). Thus, it is more accurate to describe the TMS effects as modulation, rather than inhibition or facilitation. The advantage of TMS is not only that it can be used to give an idea of which cortical area is involved in a certain function, but also that it can be used to obtain information of the time course of that involvement.

TMS studies have shown that the LIFG is involved in language processing at certain time points. Through the use of repetitive TMS (rTMS) (10 Hz, 3 pulses, 110% MT) Devlin, Matthews and Rushworth (2003) demonstrated the involvement of the anterior part of LIFG in a semantic decision task. In a lexical decision task Zhu, Gold, Chang, Wang & Juan (2015) detected a slowing down of RTs, when the anterior part of the LIFG was stimulated 150 ms post-stimulus onset. Combining offline and online rTMS, Hartwigsen, Weigel, Schuschan, Siebner, Weise, Classen & Saur (2015) have shown the role of the anterior LIFG and the angular gyrus in semantic processes. They applied offline rTMS (50 Hz, 600 pulses, 80% AMT) to inhibit the angular gyrus and online rTMS (10 Hz, 4 pulses, 80% AMT) to modulate the anterior LIFG. The involvement of the posterior LIFG was shown at 300 ms post-stimulus onset in a naming task (Schuhmann, Schiller, Goebel & Sack, 2012). Posterior LIFG is also involved in syntactic processing (Acheson & Hagoort, 2013; Sakai et al., 2002).

Despite the significant amount of evidence for the involvement of the LIFG and other brain areas in language processing, there are still questions to be answered in this area of research. A basic problem in current neuroimaging and TMS studies is that most of the experiments are conducted using either single word production or sentence comprehension tasks.

While many of these studies are carefully controlled and elegantly designed, neurolinguistic studies on the production of grammatical dependencies are still scarce. Shapiro, Pascual-Leone, Mottaghy, Gangitano & Caramazza (2001) attempted to investigate such dependencies in single word production (the participants were cued to produce verbs in their first and third person singular forms and nouns in their singular and plural forms). They used offline rTMS (1 Hz, 300 s, 110% MT) to demonstrate that the left midfrontal gyrus was involved in verb retrieval but not in noun retrieval. The authors further concluded that the target area was also involved in grammatical processing. The lack of studies examining multi-word production is reasonable, as there are many methodological issues to take into account. First, it is difficult to control what the individual produces. Second, more confounds are involved, as the number of words to be produced increases. Third, stimulating language areas can cause facial twitches due to peripheral nerve stimulation, which in turn makes language production more difficult (Devlin & Watkins, 2007).

There are, however, a limited number of electroencephalography (EEG) and magnetoencephalography (MEG) studies which use multi-word production paradigms to show the time course and the order in which the components of the phrase are being planned (Pylkkännen, Bemis & Elorrieta, 2014; Michel Lange, Perret & Laganaro, 2015; Bürki, Sadat, Dubarry & Alario, 2016; Bürki & Laganaro, 2014; Eulitz, Hauk & Cohen, 2000; Habets, Jansma & Münte, 2008). Eulitz et al. (2000) failed to detect an EEG signal difference between adjective-noun and isolated noun naming in German. Michel Lange et al. (2015), however, showed that adjective-noun phrases take longer to plan than isolated nouns in French. They suggested that the planning of the second word (in this case the adjective) can already begin when the first word is encoded at the phonological encoding level. In an English experiment, using MEG Pylkkännen et al. (2014) also identified a difference between isolated noun ('cat') and adjective-noun ('black cat') phrase production. The difference occurred at 180 ms post-stimulus. They argued that at this time point the grammatical encoding (the combination) of the two words happen. A similar temporal difference (190-300 ms post-stimulus onset) was observed by Bürki & Laganaro, 2014 in a determiner-adjective-noun phrase ('the big cat') study. They suggest that at around 190 ms the noun and the adjective are planned in parallel, followed by the determiner. In a determiner-noun phrase ('the cat') study, Bürki et al. (2016) further that the noun and the determiner are planned sequentially, with the noun being the first element to be planned. The latter possibly happens because the gender of the determiner is dependent on the gender of the noun and thus it cannot be planned prior to the noun.

With the current TMS experiment, we aim at taking further multi-word production studies and investigating the cortical areas involved in language processing (more specifically, grammar and lexicon), using a determiner-adjective-noun phrase paradigm. The advantage of this paradigm is that the phonological outputs of the two linguistic tasks are nearly perfectly matched and thus the findings will be easier to interpret. Our study may contribute to the current understanding of the neural underpinnings of language and provide directions for the development of new multi-word production paradigms.

For the sake of simplicity, we focus solely on the role of LIFG in language production. We expect that the anterior part of LIFG (BA 47) is involved in the lexical-semantic planning, while the posterior part of LIFG (BA 44) is involved in grammatical planning (Price, 2010). Therefore, reaction times (RTs) should be more altered in the grammatical condition when BA 44 is stimulated and in the lexical condition when BA 47 is stimulated. We stimulate at 100 ms post-stimulus onset for 300 ms in order to modulate the early processes of utterance planning, which may include the combinatorial processes or the lexical retrieval, and in order to minimize the risk of covering phonological processes.

The current experiment is carried out in Danish, in which, like in other Germanic languages, the attributive adjective and the determiner agree in gender and number with the noun. As a target grammatical item we take the indefinite article ‘a’ (*en* or *et* in Danish) and contrast it to its almost homophonous lexical counterpart, which would be the numeral ‘one’ (also *en* or *et* in Danish). We thus contrast utterances like ‘a red letter’ with utterances like ‘one red letter’, but due to the homophony (apart from stress differences) between articles and numerals we minimize the phonological contrast. Our assumptions about grammatical and lexical items are based on Boye & Harder’s (2012) theory, which among other things suggests that lexical items can convey the main point of the utterance, while grammatical items carry only secondary information. The theory thus provides a semantic difference between grammar and lexicon.

5.2 Materials and methods

5.2.1 Participants

Twenty healthy native speakers of Danish were recruited for the study (10 male, aged between 18 and 34). They did not report a history of a neurological or a psychiatric disorder and they had (corrected to) normal vision. All of the participants were screened for MR and TMS safety prior to the experiment. Two of the participants dropped the study after the structural T1 weighted MRI image acquisition session. Another two could not continue due to TMS side effects (see data analysis for details). One participant’s motor hotspot (the cortical area, stimulation of which causes twitches in the thumb) could not be found. The data acquired from one of the participants could not be used due to a technical issue, and another participant had to be excluded due to strategy usage, which resulted in RTs below 200 ms. Overall, data from 13 individuals were analyzed.

5.2.2 Study design

We used a 2x2x2 factorial design with the factors TMS-site (BA 44/BA 47), stimulation type (effective/sham) and task (grammatical/lexical). The experiment consisted of one MR and two TMS sessions on different days. The participants could skip the MR session, if they already had T1 weighted images acquired in the last two years through the same scanner. One of the TMS sessions was a sham session with low intensity stimulation and the other one was an effective stimulation session (Figure 5.1). There was an interval of at least one week between the two TMS sessions. The first and second TMS sessions were scheduled at the same day of the week and at the same time of the day. Each TMS session started with a preparation, neuronavigation and motor threshold (MT) detection, which was followed by a short break. During the break, the electrodes were taken off, the experimental computer was prepared and the instructions were given. Then the experimental session began, which consisted of two parts with a one hour break between them. In one of the two parts BA 44 and in the other one BA 47 was stimulated. The two tasks were given in blocks for each target site. There was a short break between the tasks. The sessions, sites and the tasks were counterbalanced across participants (Figure 5.1).

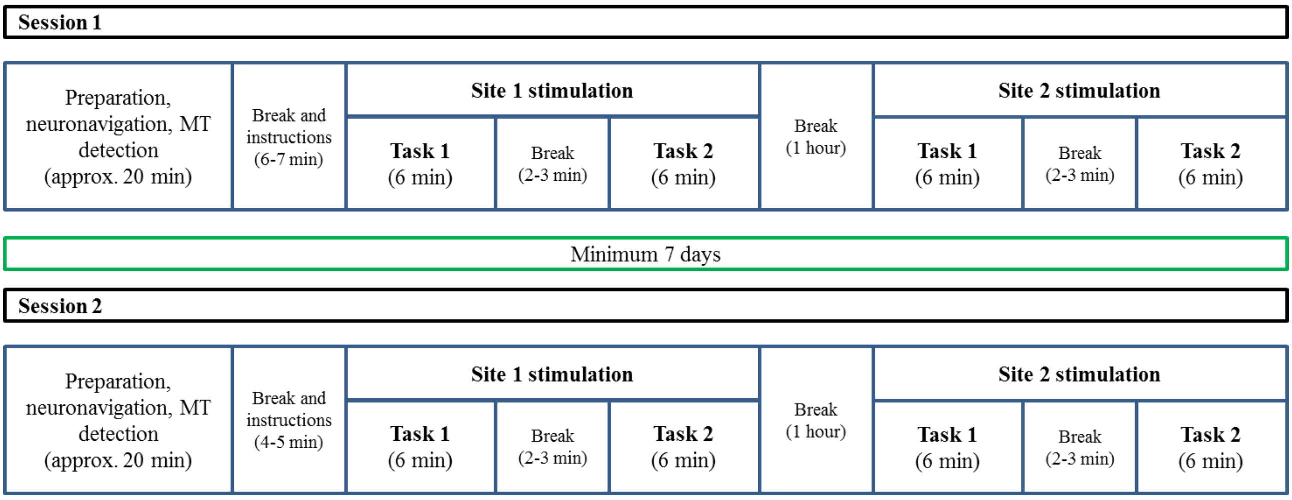

Figure 5.1 A schematic description of the two TMS sessions. Both of the sessions consisted of exactly the same components with the only difference that one of them was a sham session and the other one was an effective stimulation session and that in the second session the instructions typically took less time, as the participants were already familiar with the task. Stimulation (sham/effective), tasks (lexical/grammatical) and sites (BA 44/ BA 47) were counterbalanced across participants.

5.2.3 Materials & Procedure

The experimental paradigm was programmed and presented using PsychoPy (Peirce, 2007). The participants first read the instructions in Danish, which were subsequently explained to them by the experimenter. To avoid errors due to naming variability, the participants were presented with the possible nouns occurring in the experiment: they first saw the objects with the nouns written underneath and then they had to name the nouns while presented without the nouns. Afterwards they went through a couple of trials of the actual task, and the experimenter corrected them, if errors were made. Once they had learned the task, the real experiment began.

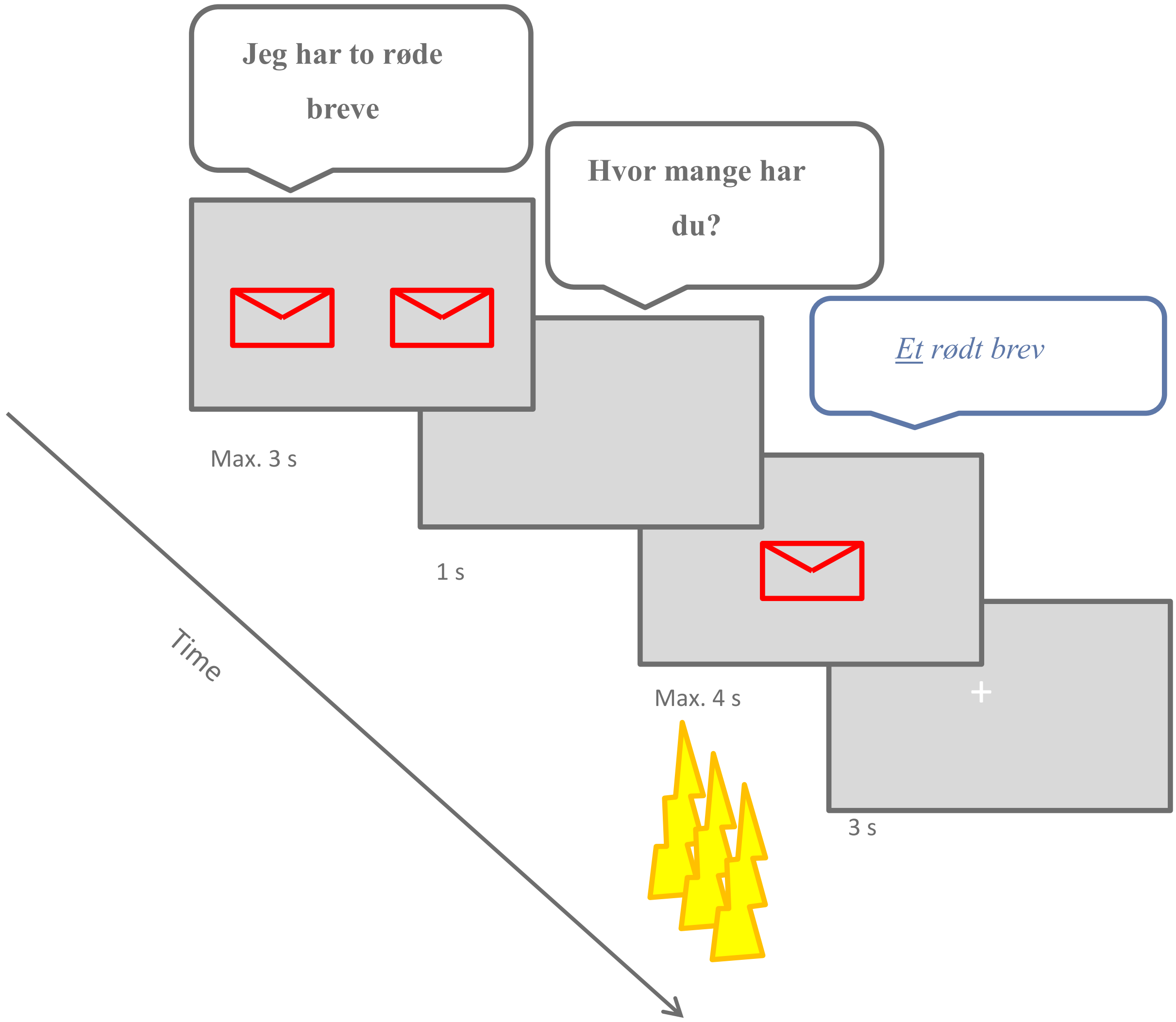

Figure 5.2 The timeline of one experimental trial in the lexical task. The participant sees a picture and hears a voice saying *Jeg har to røde breve* ('I have two red letters.'). Then a blank screen appears and the participant hears the question *Hvor mange har du?* ('How many do you have?'). It is followed by the target picture, when the participant has to give the expected response *Et rødt brev* ('One red letter'). 100 ms after the target picture appears on the screen the participant receives the three TMS pulses. Before the next experimental trial starts, a fixation cross appears.

The participants saw a line drawing in different colours, representing a Danish concrete noun and heard a female voice saying either (1) type of a sentence or (2) type of a sentence, depending on the block. Next, the participants saw another picture and they had to respond accordingly (Figure 5.2). The two tasks in the paradigm corresponded to grammatical (1) and lexical (2) conditions. Lexical numerals (like English *one*) (1) were contrasted with grammatical indefinite articles (like English *a/an*) (2). In both tasks, the expected responses were phonologically similar and only differed in terms of stress and contrast (number and colour).

(1) *Jeg har et rødt brev. Hvad har du?*
 ‘I have a red letter. What do you have?’
 Expected response: *et blåt brev.*
 ‘A blue letter.’

(2) *Jeg har to røde breve. Hvor mange har du?*
 ‘I have two red letters. How many do you have?’
 Expected response: *et rødt brev.*
 ‘One red letter.’

The tasks were presented in blocks. Each block consisted of 32 target and 8 filler items. For the filler items, the participants saw two objects on the screen as a stimulus and had to respond accordingly. The full list of the items can be found in Appendix C. The screen was placed 70 cm from the participants. The responses were recorded using a microphone. RTs were extracted through *Praat* (Boersma, 2002) by an assessor naïve to the aims of the experiment.

5.2.4 Transcranial magnetic stimulation parameters

Biphasic TMS pulses were applied, using the *MagVenture X100* stimulator (MagVenture A/S, Farum, Denmark) through a manually held *MagVenture Small Cool-Butterfly B35* coil (inner diameter 23 mm, outer diameter 46 mm) for the resting motor threshold (RMT) detection and a *B35* coil attached to the TMS robot arm. RMT was defined using the TMS *Motor Assessment Tool (MTAT 2.0)*, which provides parameter estimation by sequential testing (PEST) procedures using the Maximum-Likelihood strategy for estimating motor thresholds. For the sham condition, 30% of the resting motor threshold was applied (16-28% of the stimulator output) and for the effective stimulation 110% of the resting RMT was applied (55-99% of the stimulator output). Three pulses with a frequency of 10 Hz were applied 100 ms after the target picture was presented.

5.2.5 TMS Localization

The target sites were located using neuronavigation through robotized TMS system (*TMS Navigator robotic edition*, Localite GmbH, Sankt Augustin, Germany; Axilum Robotics TMS Robot). The participants’ head was co-registered onto their own T1-weighted image. The brain images were obtained prior to the TMS session with a *Philips Achieva 3-Tesla* scanner

(Philips Achieva, Best, The Netherlands) with the following parameters: 50 slices, TE = 70 ms, TR = 12.2 s, b-value = 1000/2000 s/mm^2.

The Talairach coordinates for the target sites (for BA 44 x = -52, y = 10, z = 28 and for BA 47 x = -46, y = 33, z = -3) were converted to MNI coordinates. The target site was determined in the neuronavigation software and the robot arm moved to the target area accordingly.

5.2.6 Data Analysis

Data from three participants could not be collected, as two of them dropped out after the MR session. We were unable to find the motor hotspot of the third one, which was necessary for determining the motor threshold and thus the stimulation intensity. Additionally, data from three participants were excluded from the analysis. One of these participants could not continue due to facial muscle contractions. The second one reported blurred vision and had to discontinue the session. The third participant had to be excluded due to technical issues regarding the sound recording. The individual RTs (Figure 5.3) showed that, among the remaining participants, one participant was remarkably faster than the others when performing the lexical task in both effective and sham stimulation. During the experimental session the participant admitted using a strategy. Many of his data points ended up being below 200 ms and some of them even below 100 ms, which cannot be counted as genuine (Luce, 1986). We thus excluded this participant from further analysis. The remaining data pertain to 13 individuals.

Incorrect responses of the remaining participants were also excluded from the RT analysis (2.5 % of the remaining data points). A response was counted as correct, if all the components of the expected response (determiner, adjective and noun) were present, the agreement was grammatically correct and the noun and the colour were identical to those of the expected response. We did not remove any outliers, as the residuals were normally distributed and thus the data met the assumptions of linear mixed models (Winter, 2015).

We used linear mixed models to analyze the data. Stimulation (effective/sham), area (BA 44/47) and task (gram/lex) were defined as fixed effect variables. The primary outcome variable was RT but we looked at accuracy as well (using a generalized linear mixed model with binomial family instead). Item and participant were random effects. The data were analyzed using the lme4 package (Bates, Maechler, Bolker & Walker, 2015) of *R* (R Core Team, 2014). The step function from the same package was used to determine the best fitting model.

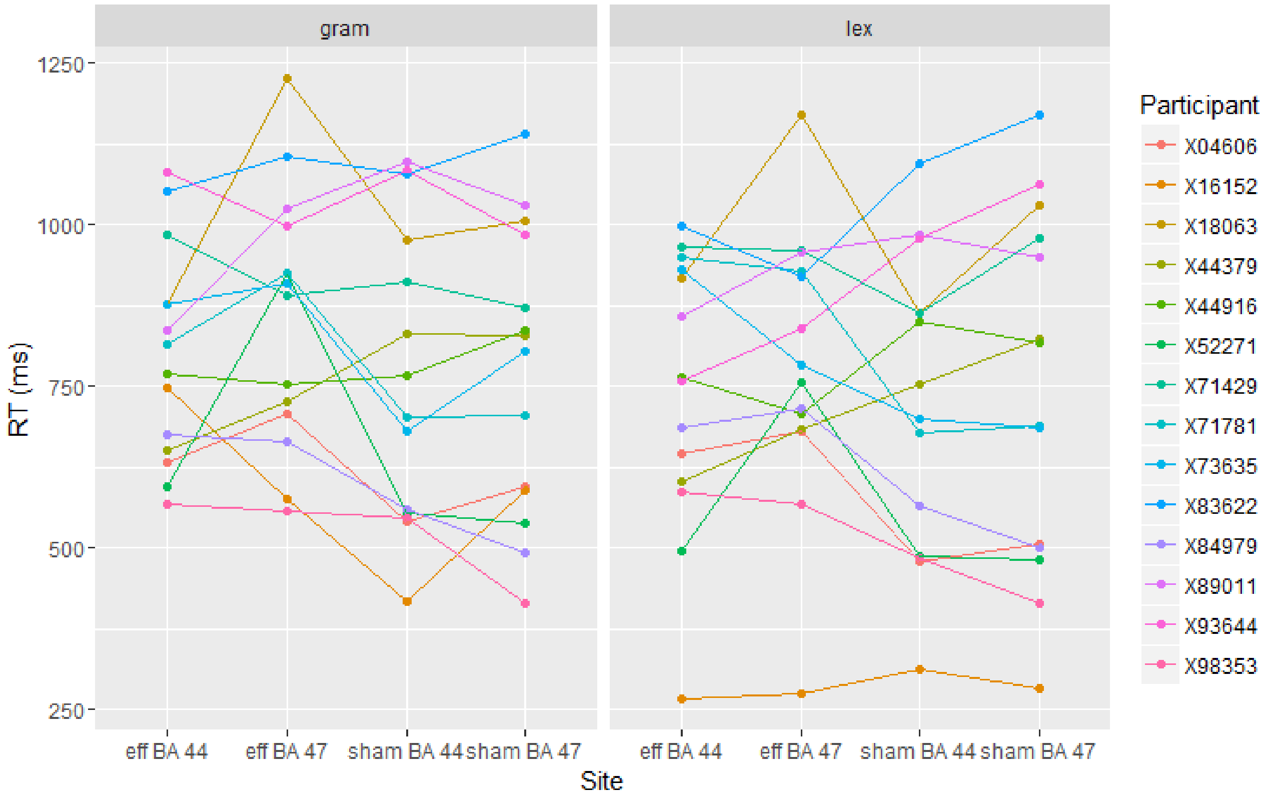

Figure 5.3 Individual reaction times (RTs, n = 14) (eff = effective, gram = grammatical, lex = lexical). Participant *X16152* is remarkably faster than the others in both effective and sham stimulation and both BA 44 and BA 47 when performing the lexical task. He reported that he was using a strategy.

5.3 Results

The descriptive statistics for the remaining 13 participants can be found in Table 5.1. The best fitting model suggested by the step function includes the three fixed effect variables as main effects and their three-way interaction.

According to the model, the main effect of site is significant (b = 73.7, t (3200) = 6.31, p < 0.001), indicating that RTs for the grammatical task are slower in BA 47 compared to BA 44 in effective stimulation (we were expecting alterations in RTs in the grammatical condition, when stimulating BA 44, and in the lexical condition, when stimulating BA 47). There is, however, no significant difference in RTs between grammatical and lexical tasks in BA 44 in effective stimulation (b = -18.55, t (3200) = -1.59, p = 0.112), or between the grammatical task in BA 44 in effective stimulation and the grammatical task in the sham stimulation (b = -5.35, t (3200) = -0.46, p = 0.646). The two-way interaction both between site and task (b = -39.39, t (3201) = -2.38, p = 0.018) and between site and stimulation (b = -

9.66, t (3200) = -4.822, $p < 0.001$) is also significant, while the interaction between task and stimulation is not (b = -23.69, t (3201) = -1.44) (Table 5.3).

Table 5.1 Mean ± SD reaction times (RT) and accuracy for two sites (BA 44 and 47), two stimulation types (effective and sham) and two tasks (grammatical and lexical)

n = 13	**Effective**		**Sham**	
	RT ± SD (ms)	**Accuracy (%)**	**RT ± SD (ms)**	**Accuracy (%)**
BA 44				
Grammatical	801 ± 204	99	792 ± 249	98
Lexical	780 ± 206	97	750 ± 251	98
BA 47				
Grammatical	875 ± 236	97	788 ± 262	97
Lexical	812 ± 212	98	776 ± 239	98

Table 5.2 The summary of the reaction time (RT) results. Site (BA 44 and 47, where BA 44 is the baseline), Task (grammatical and lexical, where grammatical is the baseline) and Stimulation (effective and sham, where effective is the baseline)

	b	***SE***	***df***	***t***	***p***
Intercept	799.95	50.76	13	15.76	< 0.001
Site	73.70	11.68	3200	6.31	< 0.001
Task	-18.55	11.67	3201	-1.59	0.112
Stimulation	-5.35	11.64	3200	-0.46	0.646
Site x Task	-39.39	16.57	3201	-2.38	0.018
Site x Stimulation	-79.66	16.52	3200	-4.82	< 0.001
Task x Stimulation	-23.69	16.50	3201	-1.44	0.151
Task x Stimulation x Site	69.93	23.39	3200	2.99	0.003

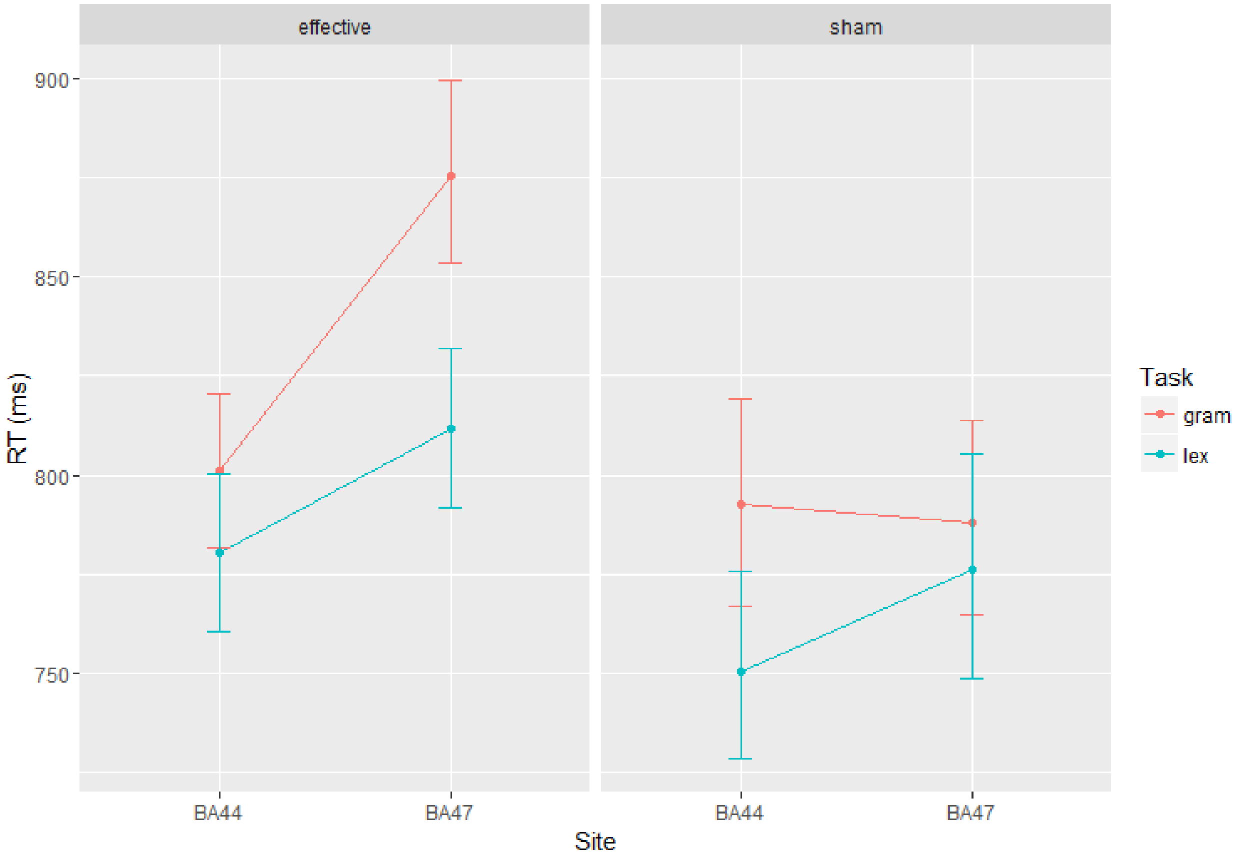

Figure 5.4 The three-way interaction shows that the reaction times (RTs) difference between the grammatical (gram) and lexical (lex) task is bigger in BA 47 in effective stimulation.

Table 5.3 The summary of the accuracy results. Site (BA 44 and 47, where BA 44 is the baseline), Task (grammatical and lexical, where grammatical is the baseline) and Stimulation (effective and sham, where effective is the baseline)

	b	*SE*	*z*	*p*
Intercept	44.3	0.45	9.84	<0.001
Site	-0.80	0.49	-1.63	0.1023
Task	-0.71	0.49	-1.45	0.1478
Stimulation	-0.16	0.55	-0.29	0.7733
Site x Task	1.18	0.66	1.78	0.0765
Site x Stimulation	0.24	0.68	0.35	0.7232
Task x Stimulation	0.35	0.69	0.50	0.6166
Task x Stimulation x Site	-0.25	0.95	-0.27	0.7889

The results also show a significant three-way interaction (*b* = 69.93, *t* (3200) = 2.989, *p* = 0.003). In other words, the RT difference between grammatical and lexical task is significantly bigger in BA 47 and in effective stimulation, compared to BA 44 and sham (Figure 5.4).

None of the fixed effect variables had a main effect on accuracy. A significant interaction was not detected either (Table 5.3). There were 75 erroneous responses in total. The errors belonged to the following categories: 26% disfluencies, 14% agreement errors, 3% insertions of words that were not part of the target utterance, 8% omissions of one or more components of the target utterance and 22% substitutions.

5.4 Discussion

The current study attempts to contribute to our understanding of the neural underpinnings of language, using a multi-word production paradigm in a TMS study. We stimulated BA 44 and BA 47, while the participants performed a grammatical and a lexical task. We showed a three-way interaction (site by stimulation by task), indicating that BA 47 is more involved in the grammatical task than in the lexical task. These findings are not in line with our predictions which we based on the literature. Earlier findings suggest that BA 47 is involved in lexico-semantic encoding (Dapretto & Bookheimer, 1998; Hagoort et al., 2004; Price 2010; 2012; Devlin et al., 2003; Hartwigsen et al., 2016). The fact that our results do not support this involvement may be explained by the specific paradigm we used and the order, in which individual components of the utterance are planned. In our paradigm, the two tasks had both grammatical and lexical components but the grammatical task had one additional grammatical item and one additional dependency, while the lexical task had one additional lexical item. It is possible that the determiner in the grammatical task and the numeral in the lexical task are the last items to be retrieved, as they are dependent on the gender of the noun (as shown by Bürki et al., 2016). Moreover, the stimulation is given at the point of grammatical encoding, where most probably the noun and the adjective are being retrieved and then the determiner follows (Bürki & Laganaro, 2014). As a result, the TMS pulses are likely to affect the retrieval of the adjective and the noun to a larger extent than the determiner. The effect of TMS is, however, not as big on the lexical task because there is no colour contrast in the lexical task and the participant simply has to repeat the colour he or she has just heard. In other words, at that particular time course the only "new" word that needs to be retrieved is the colour in the grammatical condition. The noun in both tasks and the colour in the lexical task are repeated in the target utterance, and therefore they may be pre-activated by the cue. Thus, it is possible that the stimulation affects the adjective and not the determiner or numeral retrieval.

It is important to note, however, that to our knowledge there is no evidence as to the order, in which numeral-adjective-noun phrases are being planned. One could speculate that while in our paradigm the gender of the numeral is dependent on the noun, the number of the noun depends on the numeral. Therefore, it is reasonable to assume that unlike the determiner, the numeral is involved in some kind of parallel processing. The current setup of the experiment, however, does not allow any conclusions about such a phenomenon.

There may be several reasons why we did not find any effect of BA 44 stimulation on tasks. As we had only one time point (100 ms post-stimulus onset), we could only examine the early effects of stimulation. It is possible that BA 44 is involved in a later stage of language planning and at phonological level (Indefrey & Levelt, 2004; Schuhmann et al., 2011). To detect such an effect, it would have been necessary to include an additional time point in the study design. However, we did not use such a design to avoid having more than the maximum recommended number of predictor variables (Field, 2012). Future research targeting BA 44 at early and late time points post-stimulus would shed light on the involvement of this area.

Another reason why we did not find an effect of BA 44 could be related to the fact that the activation of BA 44 has been mostly shown in syntactic comprehension (Hagoort, 2005; Dapretto & Bookheimer, 1998; Caplan & al., 1998; Friederici et al., 2009; Cappa, 2012). Although Papathanassiou, Etard, Mellet, Zago, Mazoyer and Tzourio-Mazoyer (2000) have shown that BA 44 is activated both in language production and comprehension, they used a single word production paradigm in their study. Therefore, the involvement of BA 44 in language production combinatorial processes is not conclusive.

A third reason for the lack of effect of BA 44 could be that BA 44 is only involved in syntactic processes that do not include grammatical item retrieval (Grodzinsky, 2000). In addition to that, the theory we based our assumptions on (Boye & Harder, 2012), among other things suggests that grammar is an information prioritization device and as such the difference between grammar and lexicon is also semantic. Thus, it should not be surprising that in our study BA 47 and not BA 44 is involved in grammatical retrieval.

Although we limited our study to two parts of the LIFG, there are many more cortical regions involved in language processing (Price, 2010). Especially the role of the left middle temporal gyrus in lexical retrieval should not be ignored (Indefrey & Levelt, 2004; Schumann et al., 2011; Price, 2010). It is thus important to further investigate the role of other cortical areas in multi-word production tasks, using TMS.

Despite the challenges of a multi-word production paradigm in a TMS study, we succeeded in showing BA 47 involvement in language production planning. The current study is only a starting point for the investigation of causal relationships between cortical areas and multi-word production paradigms. Future research can expand this paradigm to other cortical areas, such as the temporal cortex, and other time points in the language planning.

CHAPTER 6

General conclusions

In this project I integrated a neurocognitive model and a linguistic theory that position themselves between the two extremes of modularity and connectionism, and of Generative and Construction Grammar (Mogensen, 2014; Boye & Harder, 2012). The hypotheses of each of the studies described in the previous chapters arise from one or both of the theories. The results of the studies show a potential for a successful integration. Below I summarize the findings in the previous four chapters in relation to the research questions mentioned in the introductory chapter.

6.1 Grammar - lexicon distinction in agrammatic and healthy speakers

One of our main aims was to derive and test predictions about processing differences between grammar and lexicon based on the Boye & Harder (2012) theory. Boye & Harder's (2012) theory proposes a distinction between lexical and grammatical pronouns in French that no other theory proposes. In the third chapter we classified all French pronouns into grammatical and lexical according Boye & Harder's (2012) theory. We further showed a dissociation of grammatical and lexical pronouns in French speakers with agrammatism, which were not limited to clitic and non-clitic personal pronouns. Such findings are in line with what has been previously reported about non-clitic personal pronouns being relatively spared in agrammatism (Nespoulous et al., 1990; Lonzi & Luzzatti, 1993; Stavrakaki & Kouvava, 2003; Chinellato, 2004, 2006; Rossi, 2007). Our results further generalize the dissociation to other pronouns, such as demonstratives and possessives. Thus, we not only provided additional evidence for pronoun dissociation in agrammatism but also accounted for it through a linguistic theory.

In Chapter 4 we examined the grammar-lexicon distinction in Danish through a language production study. We added a WM load to investigate, among other things, whether grammar requires more load or not. Through lower accuracy in the grammatical condition we showed that the grammatical task was more difficult than the lexical one, while RTs did not differ. Such a finding indicates that there is a processing difference between homophonous grammatical and lexical items in terms of dependency. More specifically, a near-homophonous utterance is more difficult to process when there is an extra grammatical dependency. Through error analysis we also showed that the participants tended to omit the grammatical *en/et* but not the lexical one, thus indicating that grammatical items have less priority and can be dropped under constraints.

The TMS study (Chapter 5) provided evidence that BA 47 is differently involved in a specific task performance. Our findings, however, are not sufficient for strong claims about the cortical localization of grammar and lexicon.

6.2 Working memory and language in aphasia and healthy population

Our aim was to investigate the shared resources between WM and language processing. More specifically, we were looking for evidence about WM involvement in various levels of language processing. Through a literature review (Chapter 2) we showed that the WM deficits in aphasia vary across aphasia types. Lesion location, measurement method used and reorganization processes largely affect the varied findings across individuals. However, we suggest that the causal relationship between WM limitations and linguistic deficits in aphasia mostly depend on the amount of shared neural substrate lost to injury, the reorganization processes taking place after the injury and the specific task used for measuring WM.

In Chapter 4 we showed that WM and language production share a system at a phonological level, which is in line with previous suggestions that WM and language production interact at phonological level (Acheson & MacDonald, 2009). On top of that, a more erroneous production in the grammatical condition in the form of article omissions suggests that there is some kind of an interaction at the grammatical level, too. Interestingly, we did not detect similar error pattern in the TMS study (Chapter 5), where we used the same language production paradigm, as in Chapter 4 but without the WM load. The omission of grammatical items when load is added is in line with agrammatism theories, suggesting resource limitations (Caplan, 2012; Miyake et al., 1994, Kolk, 1995). We showed such a limitation by adding an extra load to a healthy brain, which resulted in omissions of a grammatical item, as it is observed in agrammatism.

Using WM as an example, we also showed the interaction between language and another cognitive function. We thus demonstrated their relative independence and being part of one bigger system at the same time. Therefore, it is reasonable to assume that indeed the cognitive system is organized somewhere between the extreme poles of modularity (e.g. Pinker, 1999) and connectionism (e.g. Bechtel & Abramsen, 1991).

6.3 The REF-model in the healthy and the injured brain

We investigated predictions derived from the REF-model. Through shared neural substrate and shared AMs the REF-model predicts the possibility of shared resources between language and WM. Using the assumptions of the REF-model (Mogensen, 2011, 2014), in Chapter 2 we described the possible interaction between WM and language and the reorganization, following a brain injury. The REF-model accounts for the contradictory findings pertaining to WM and language. The model also emphasizes the importance of the choice of the WM measurement task, as depending on the task, different surface phenomena may be observed at a surface level. The REF-model also suggests that those contradictory findings are a result of the loss of specific EFs and unique recovery mechanisms, which result in new albeit imperfect ASs.

In Chapter 4 we investigated the possibility of shared resources between the language production and WM ASs. We revealed a facilitation of production, as WM load increased, which was in line with a previous finding (Power, 1985). Such facilitation may have been a result of a task-specific AS that was created during task performance. Thus, the tasks chosen to measure a cognitive function are important and should always be taken into account, when carrying out cognitive experiments.

The REF-model (Mogensen, 2011, 2014) also accounts for reorganization of language in the brain following an injury. Through the interaction of existing EFs new ASs are created. Those in turn manifest into "recovered" surface phenomena, which are not identical to the pre-injury functions. Depending on pre-injury neural connections and post-injury experience, the recovered functions vary across individuals. In Chapter 3 we showed the possibility of reorganization of grammar, following a brain injury, which resulted in a recovered, yet imperfect grammar. Some of the individuals with agrammatism had constructed grammatical structures unique to them, which may be a manifestation of imperfect ASs. However, longitudinal data are necessary to further examine this process.

6.4 Future directions

With this thesis I have intended to contribute to the knowledge about language processing and its neural underpinnings. While the first two studies used rather traditional methods (Chapters 2 and 3), the third and the fourth (Chapters 4 and 5) provided a slightly novel approach to language production research. The multi-word production paradigms are quite new to language research, and there are a limited number of studies investigating language production in relation to WM. This project is only the beginning of something that could become an important contribution to cognitive research. Future research will shed light on the questions that remain unanswered in this thesis.

A pronoun elicitation study in a larger sample of individuals with agrammatism would provide more solid evidence about the pronoun dissociation we described in French (Chapter 3). Carrying out such a study longitudinally would give the opportunity of investigating the post-injury reorganization of language, predicted by the REF-model. To further investigate the causal relationship between WM and language in injured population, it is necessary to conduct WM and language production experiments in individuals with aphasia. One such experiment could be the one we carried out in healthy population (Chapter 4).

To further develop the language production and WM span tasks described in Chapter 4, items other than concrete nouns could be used to add the load. For instance, to further explore whether grammar requires more load, grammatical items or utterances containing grammatical items can be used to create the WM load. Non-words can be used to evaluate whether only lexical words have such a facilitatory effect on RTs or generally any kind of phonological load causes facilitated production.

The production task used in Chapter 5 may have been too easy for non-injured individuals, which resulted in a ceiling performance. Therefore, we were not able to carry out error analysis. It would be interesting to further use the task (perhaps adding a WM load, like in Chapter 4) in individuals with aphasia, as their performance most probably would not be at a ceiling level. In addition to that, a more complex task could also result in more errors in an experiment with healthy individuals, using TMS. The paradigm in Chapter 5 can be further used in a TMS study, stimulating other brain areas at different time points to investigate the spatiotemporal relationship between a language function, time course and a cortical area.

In a wider perspective, the current thesis also suggests a number of directions for future studies of the neurocognitive underpinning of grammar. The experiments described in this thesis may be carried out across various languages to ensure crosslinguistic applicability. Longitudinal research would allow further observing the recovery patterns of individuals with aphasia and thus providing more evidence for the REF-model. Understanding how language is organized in the brain and how it reorganizes following a brain injury would not only contribute to cognitive science but also provide new directions for treatment of individuals with aphasia and further social reintegration. Moreover, the crosslinguistic knowledge gained from integrating the REF-model (Mogensen, 2011; 2014) and Boye & Harder's (2012) theory can also be used for facilitating second language acquisition. The REF-model predictions could answer the questions on how the previous experience of an individual could be used to more efficiently create ASs for the new language. If Boye & Harder (2012) are correct in defining grammar as dependent on lexicon, it may be possible to facilitate the acquisition of foreign grammar by building it on lexicon.

The main limitation of this project is the variety of the methods used for conducting research. However, while it is challenging to draw conclusions from such different studies, each of them also serves as a stepping stone to develop new directions and to combine one method with the other (for instance, examining language production and WM using TMS). It is thus important to stop here and to continue the further contribution to cognitive research to understand how language is organized in the brain.

APPENDIX A

Table A.1 Individual information about the participants with aphasia taken from Sahraoui & Nespoulous (2012)

	Age	**Gender**	**Years of education after junior high school**	**Handedness**	**Etiology**	**Post-onset** (years; months)	**Aphasia type and severity**
BR	52	M	6	Ambidexter	LH ischemic stroke	6;7	Broca's aphasia with agrammatism, severe
MC	44	M	14	Right	LH ischemic stroke	4;0	Broca's aphasia with agrammatism, mild
PB	41	M	9	Left	LH ischemic stroke	9;1	Broca's aphasia with agrammatism, mild
PC	51	M	2	Right	LH ischemic stroke	1;3	Broca's aphasia with agrammatism, severe
SB	56	M	7	Ambidexter	LH ischemic stroke	4;6	Broca's aphasia with agrammatism, severe
TH	74	F	0	Right	LH ischemic stroke	2;8	Broca's aphasia with agrammatism, mild, well recovered

Table A.2 The sample sizes (number of words), words per minute (WPM) and mean length of utterance (MLU) for each participant with aphasia and the range for the control group per task

Participant	**Autobiography**			**Narrative**			**Descriptive**		
	Sample Size (words)	*WPM*	*MLU*	*Sample Size*	*WPM*	*MLU*	*Sample Size*	*WPM*	*MLU*
BR	705	32	3,8	177	23	3,4	297	23	4,1
MC	599	55	5,8	323	41	7,2	580	39	7,5
PB	777	69	7,5	1081	69	10,6	1379	62	11
PC	760	38	5	383	32	7,5	327	23	5,1
SB	541	47	4,8	542	34	7,3	619	34	8,3
TH	671	75	8,5	324	43	11,57	530	57	9,6
Control (range)	339 – 841	122 - 191	9 – 13	342 - 1233	111 - 179	8,1 – 14,6	467 - 1139	137 - 201	9,8 – 13,2

Speech samples of individual participants with agrammatism

BR: Un petit euh euh toi une un petit fille… aller… aller euh euh… beaucoup des arbres [ave] une euh…

Exp: Alors c'est dans

BR: La forêt pour aller rendre visite en une dame euh euh grand-père non non…

MC: Et euh le loup euh "bonjour ça va" euh. et après après euh la fillette voit le loup. et… décédée. Ou je sais pas… je sais pas.

PB: Et hum la femme qui euh fait euh euh c'est euh une course dans la forêt. Euh c'est hum je sais pas si c'est euh une ferme ou c'est euh ou c'est un… je sais pas…et euh la mère c'est euh u- un un pot de de de de ah d- confit- de confiture non de…

PC: Elle [ef] e- elle fait elle fait la elle fait la galette. Elle porter… hum la maman euh oui la maman. Alors [ɛ̃k] euh [ɛlRakõt] non elle rencontre oui elle rencontre euh euh le loup un loup… bon. Et hum… le loup euh non euh non non euh le loup… ah-non.

SB: Donc hum… la maman euh… vient vient non en-fait euh vient non. A- aller le chaperon rouge. Hum… traverser la forêt pour la rencontrer le grand-mère. Euh… dans le panier alors je sais pas-du-tout du beurre non. Je sais pas c’est ça.

TH: Et elle s'en va. Et euh elle rencontre le loup. En deux alors elle lui ce qu'il va faire. Alors elle il est parti avant. Et il a pris mangé le [lɑ̃] grand-mère prend sa place dans le lit. Alors euh le la petite fille me dit que la tête de son p- son son ah sa grand-mère a changé de tête.

APPENDIX B

Table B.1 The list of pronouns classified as grammatical or lexical in the current study

Pronoun	**Type of pronoun**	**Grammatical or lexical**
je, me, m’, tu, te, t’, il, ils, se, s’, en, y, le, la, l’, les, nous, vous, elle, elles, lui, leur	clitic personal pronouns	grammatical
moi, toi, lui, soi, eux, nous, vous, elle, elles	non-clitic personal pronouns	lexical
ce, c’, cet, cette, ceux	adnominal demonstrative pronouns	grammatical
celui, celui-ci, celui-là, celle, celle-ci, celle-là, celles, celles-ci, celles-là, ceci, cela, ça, le premier, la première, les premiers, les premières, le dernier, la dernière, les derniers, les dernières	free standing demonstrative pronouns	lexical
mon, ton, son, ma, ta, sa, mes, tes, ses, notre, votre, leur, nos, vos, leurs	adnominal possessive pronouns	grammatical
le mien, le tien, le sien, la mienne, la tienne, la sienne, les miens, les tiens, les siens, les miennes, les tiennes, les siennes, le nôtre, le vôtre, le leur, la nôtre, la vôtre, la leur, les nôtres, les vôtres, les leurs	free standing possessive pronouns	lexical
on	non-focalizable indefinite pronouns	grammatical
un, une, l’un, l’une, les uns, les unes, un autre, une autre, d’autres, l’autre, les autres, aucun, aucune, aucuns, aucunes, certain, certaine, certains, certaines, telle, tels, tells, tout, toute, tous, toutes, le même, la même, les mêmes, nul, nuls, nulle, nulls, quelqu’un, quelqu’une, quelques uns, quelques unes, personne, autrui, quiconque, d’aucuns, plusieurs	focalizable indefinite pronouns	lexical
dont, qui, que, quoi, où, lequel, auquel, duquel, laquelle, à laquelle, de laquelle, lesquels, auxquels, desquels, lesquelles, auxquelles, desquelles, à qui, de qui, à quoi, de quoi	relative pronouns	grammatical
qui, que, quoi, où, à qui, de qui, à quoi, de quoi, qu’est-ce, qui, que, quoi	interrogative pronouns	lexical

APPENDIX C

Table C.1 The list of nouns used in the multi-word production tasks in Chapters 4 and 5

Noun	Gender	Syllables	Translation
bold	en	one	ball
pil	en	one	arrow
skål	ens	one	bowl
hat	en	one	hat
terning	en	two	cube
cirkel	en	two	circle
firkant	en	two	square
bælte	en	two	belt
trekant	en	two	triangle
plus	et	one	plus
hus	et	one	house
brev	et	one	letter
glas	et	one	glass
minus	et	two	minus
vindue	et	two	window
hjerte	et	two	heart
bælte	et	two	belt

APPENDIX D

Table D.1 The list of nouns used for WM load in Chapter 4

Noun	Gender	Noun	Gender	Noun	Gender
sjal	et	dæk	et	træ	et
føl	et	løg	et	sol	en
fjæs	et	kors	et	ben	et
kridt	et	kop	en	bord	et
torn	et	mus	en	krop	en
krebs	en	skab	et	doer	en
krans	en	fad	et	dyr	et
fjeld	et	stik	et	bil	en
snegl	en	ko	en	bog	en
hjelm	en	bånd	et	kort	et
saks	en	kind	en	hånd	en
ar	et	ring	en	mund	en
lås	en	kniv	en	hjul	et
boks	en	frugt	en	fjord	en
hjort	en	får	et	bænk	en
kvist	en	brød	et	ryg	en
hvalp	en	kat	en	fod	en
bær	et	sky	en	seng	en
ark	et	knæ	et	kryds	et
bur	et	sko	en	bad	et
slips	et	bjerg	et	skæg	et
ravn	en	aeg	et	blad	et
nål	en	bus	en	hest	en
spand	en	sø	en	hul	et
sejl	et	bryst	et	gris	en
hegn	et	bro	en	lår	et
lam	et	fly	et	flag	et
negl	en	bjørn	en	gulv	et
brat	et	stol	en	skib	et
ur	et	fugl	en	tag	et
søm	et	tog	et	frø	et
bål	et	fisk	en	væg	en

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