Anna Belavina Kuerten

INVESTIGATING SYNTACTIC PRIMING DURING SENTENCE COMPREHENSION IN DEVELOPMENTAL DYSLEXIA: EVIDENCE FOR BEHAVIORAL AND NEURONAL EFFECTS

Tese submetida ao programa de Pós-Graduação em Inglês: Estudos Linguísticos e Literários da Universidade Federal de Santa Catarina para a obtenção do grau de Doutora em Estudos da Linguagem.
Orientadora: Profa. Dra. Mailce Borges Mota (UFSC)
Co-orientadora: Profa. Dr. Katrien Segaert (University of Birmingham)

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Esta Tese foi julgada adequada para obtenção do Título de "Doutor em Estudos da Linguagem" e aprovada em sua forma final pelo Programa de Pós-Graduação em Inglês.

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carry the experience accumulated in these four years for the rest of my life.

ABSTRACT

Developmental dyslexia (hereafter, dyslexia) is a specific learning disorder of neurological origin primarily caused by a deficit in phonological processing (Lyon et al., 2003; Ramus, 2003; Snowling, 1995). Although considerable research in dyslexia has been devoted to a phonological deficit, rather less attention has been paid to the question to what extent other aspects of language processing are affected in dyslexia (Rüsseler, Becker, Johannes, & Münte, 2007). The present dissertation aimed at exploring sentence processing in individuals with dyslexia using the syntactic priming paradigm. More specifically, this dissertation sought to explore (1) whether dyslexics are susceptible to syntactic priming effects; (2) whether these effects are long-lasting and cumulative; (3) whether these effects are comparable to the ones observed in the control group; (4) how behavioral priming effects correlate with the brain activity measured by functional Magnetic Resonance Imaging (fMRI). The dissertation reports three studies that employed a self-paced reading task where the syntactic structure of active and passive sentences as well as the headword (the verb) were repeated between prime and target sentences. Study I and Study III investigated behavioral priming effects in 20 dyslexic and 25 control children and in 20 dyslexic and 21 control adults, respectively. Study II examined fMRI syntactic priming effects in 8 dyslexic children. The behavioral results revealed that dyslexics had stronger syntactic priming effects for passives than actives and these effects were long lasting and cumulative. In comparison to the control group, dyslexics also experienced more benefits of priming effects in the form of reduced reading time. The fMRI results showed repetition enhancement effects in the left inferior frontal gyrus (LIFG) and the left middle frontal gyrus (LMFG) for passives and a repetition suppression effect in the anterior cingulate cortex (ACC) for actives. Together, the results of the three studies suggest that stronger syntactic priming effects for the infrequent passive structure rather than the frequent active structure are due to surprisal-sensitivite persistence (Jaeger & Snider, 2007). Contrasting patterns of syntactic priming effects between two conditions (passives and actives) as well as between the two group populations (dyslexics and non-dyslexics) indicate that dyslexics differ qualitatively from non-dyslexics in processing syntax. Importantly, long-lasting and cumulative effects for passives in the dyslexic population provide support to implicit learning as the principal mechanism behind syntactic priming (Chang, Dell, & Bock, 2006).

Key words: dyslexia, dyslexic children and adults, syntactic priming, active and passive transitive sentences, verb repetition, repetition enhancement in fMRI.
Number of pages: 211 (270 with references)
Number of words: 64.540

RESUMO

A dislexia do desenvolvimento (doravante, dislexia) é um distúrbio específico de aprendizagem de origem neurológica causado principalmente por um déficit no processamento fonológico (Lyon et al., 2003; Ramus, 2003; Snowling, 1995). Embora haja um considerável número de pesquisa sobre o déficit fonológico, pouca atenção foi dada à questão de até que ponto outros aspectos do processamento da linguagem são afetados na dislexia (Rüsseler, Becker, Johannes & Münte, 2007). A presente tese teve como objetivo explorar o processamento de sentenças em indivíduos com dislexia utilizando o paradigma de *priming* sintático. Mais especificamente, esta tese procurou explorar (1) se disléxicos são suscetíveis a efeitos de *priming* sintático; (2) se esses efeitos são duradouros e cumulativos; (3) se esses efeitos são comparáveis aos efeitos observados no grupo controle; (4) como os efeitos de *priming* sintático comportamental se correlacionam com a atividade cerebral medida por ressonância magnética funcional (fMRI). A tese relata três estudos que empregaram uma tarefa de leitura automonitorada em que a estrutura sintática das sentenças ativas e passivas, bem como a palavra principal (o verbo) foram repetidas entre sentenças *prime* e alvo. O Estudo I e o Estudo III investigaram efeitos de *priming* comportamental em 20 crianças com dislexia e 25 crianças do grupo controle e em 20 adultos com dislexia e 21 controles, respectivamente. O Estudo II examinou os efeitos de *priming* sintático com fMRI em 8 crianças disléxicas. Os resultados comportamentais revelaram que os disléxicos tiveram os efeitos de *priming* sintático mais fortes para sentenças passivas do que ativas e esses efeitos foram duradouros e cumulativos. Em comparação com o grupo controle, os disléxicos também tiveram maior benefício de efeitos de *priming* na forma de tempo de leitura reduzido. Os resultados de fMRI mostraram os efeitos de *priming* na forma de aumento de ativação cerebral no giro frontal inferior esquerdo e no giro frontal médio esquerdo para passivas e efeito de supressão de ativação no córtex cingulado anterior para ativas. Juntos, os resultados dos três estudos sugerem que os efeitos de *priming* sintático mais elevados para as estruturas passivas infrequentes e não para as estruturas ativas frequentes são devidos à propriedade de surpresa (Jaeger & Snider, 2007). Padrões contrastantes de efeitos de *priming* sintático entre duas condições (passivas e ativas), bem como entre as duas populações (disléxicos e não disléxicos) indicam que os disléxicos diferem qualitativamente dos não disléxicos no processamento de sentenças. Importante, efeitos duradouros e cumulativos para passivas na população disléxica fornecem suporte à

aprendizagem implícita como o principal mecanismo por trás de *priming* sintático (Chang, Dell, & Bock, 2006).

Palavras-chave: dislexia, crianças e adultos disléxicos, *priming* sintático, sentenças ativas e passivas, repetição do verbo, aumento da ativação por repetição no fMRI.

Número de páginas: 211 (270 com referências)

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LIST OF ACRONYMS

ACC - Anterior Cingulate Cortex
ACERTA – Avaliação de Crianças em Risco de Transtorno de Aprendizagem
ADHD - Attention Deficit Hyperactivity Disorder
BA - Brodmann Area
BOLD effect - Blood Oxygenation Level Dependent effect
BP – Brazilian Portuguese
CAPES - Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
CTOPP - Comprehensive Test of Phonological Processing
DLPC - dorsolateral prefrontal cortex
DO/PO - double object and prepositional object structures
DSM-IV- Diagnostic and Statistical Manual of Mental Disorders – fourth edition
EEG - Electroencephalography
EPI - Echo-planar imaging
ERP - Event-related potential
fMRI - functional Magnetic Resonance Imaging
FOV - Field of view
FSIG - Full Scale Intelligence Quotient
FWHM - Full-width Half Maximum
GSRT - Gray Silent Reading Tests
ICD-10 – International Classification of Diseases – 10^{th} revision
IDA - International Dyslexia Association
IQ – Intelligence Quotient
LabLing - Laboratório de Linguagem e Processos Cognitivos
LIFG - Left Inferior Frontal Gyrus
LMFG - Left Middle Frontal Gyrus
M – mean
MC – main clause
MEG – Magnetoencephalography
MPI – Max Planck Institute for Psycholinguistics (Nijmegen, the Netherlands)
MUC model – Memory, Unification and Control model
NICHD - National Institute of Child Health and Human Development
PDE - Phonemic Decoding Efficiency
PIG - Performance Intelligence Quotient
PPGI - Programa de Pós-Graduação em Inglês da UFSC
PUCRS – Pontifícia Universidade Católica do Rio Grande do Sul

rANOVA - repeated-measures analysis of variance
RR – reduced-relative clause
RT – reading time
SD –standard deviation
SE – standard error
SES - socioeconomic status
SLI – specific learning impairment
SRc - subject relative clause
SRN - simple recurrent network
STG - superior temporal gyrus
STS - superior temporal sulcus
SWE - Sight Word Efficiency
TIWRE - Test of Irregular Word Reading Efficiency
TOWRE-2 - Test of Word Reading Efficiency – second edition
TR – repetition time
UFSC – Universidade Federal de Santa Catarina
VIG – verbal intelligence quotient
VWFA - Visual Word Form Area
WAIS-IV - Wechsler Adult Intelligence Scale –fourth edition
WHO - World Health Organization
WISC-III - Wechsler Intelligence Scale for Children - third edition

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CHAPTER I
INTRODUCTION

> ...the overwhelming majority of humans who have ever lived have been illiterate, and even today I believe it is the case that a very large percentage, and perhaps the majority of the world`s population have never had the opportunity to learn to read. Most of us come from families that four generations ago did not possess the ability to read. (Geschwind, 1982, p.22.)

The words of the pioneering American behavioral neurologist Norman Geschwind express well the whole idea of reading as a recently acquired skill by humans. The demand on literacy has greatly increased in the last decades with the development of the Internet and digital technologies. Therefore, in modern society, exchange of information greatly depends on the use of written language form, thus requiring people to be fluent in reading and writing. The ability to decode and encode written words has to be learned through direct instruction. The majority of children do not demonstrate lasting difficulties in acquiring this ability when formally taught. However, some children have severe difficulties with the acquisition of literacy skills. One of the reasons why they cannot reach age-adequate accuracy and fluency in reading and spelling skills is developmental dyslexia.

Developmental dyslexia (hereafter, dyslexia) is the most common developmental language disorder of neurological origin in school-age children with normal intelligence and sensory abilities (Baillieux et al., 2009; Caylak, 2009; Fisher & Defries, 2002; Fletcher, 2009; Shaywitz et al., 2001; Shaywitz et al., 2004; Vellutino et al., 2004). It is estimated that 80% of all individuals diagnosed with some type of learning disability are dyslexic (Schwartz, 2010). The estimates of the affected school-age population around the world vary from 5 to 17% (Temple et al., 2002; Gaab et al., 2007). Consequently, dyslexia may be considered as an epidemiology in the society where literacy skills are so crucial. Therefore, cases of dyslexia have attracted much research attention because it is important to understand the nature of this language disorder.

Dyslexia manifests in different languages, be they alphabetic, like English, or non-alphabetic, like Chinese (Grigorenko, 2001; Lyon et al., 2003; Nicolson et al., 2001; Shaywitz et al., 2004; Vellutino et al., 2004). Although dyslexia has been studied for more than 100 years, it is still a challenge for professionals to identify this specific learning disability, explain its underlying causes and, as a result, provide effective intervention (Démonet et al., 2004; Fisher & DeFries, 2002; Fletcher, 2009; Nicolson & Fawcett, 2008; Tunmer & Greaney, 2010; Vellutino et al., 2004).

The topic of dyslexia challenged me back in 2013 when I became a PhD student at *Universidade Federal de Santa Catarina* (UFSC), Brazil. Without any previous knowledge about dyslexia and any experience in working with learning disabled children, I was introduced by Professor Mailce Borges Mota (UFSC) to what was then a new area of research for me. Her proposal was to carry out research on dyslexia, and more specifically, to explore sentence processing of dyslexics through the phenomenon of syntactic priming. In the course of my PhD studies, I was introduced to Professor Katrien Segaert, then at the Max Planck Institute for Psycholinguistics (MPI), the Netherlands, who carefully accompanied the design of the experiments as well as the analyses of the results here reported.

It is important to state that the three studies reported in the present dissertation are part of the CAPES/NUFFIC Project 051/13 coordinated by Professor Mailce Borges Mota, on the Brazilian side, and by Professor Peter Hagoort, on the Dutch side. The CAPES/NUFFIC project is an arm of *Projeto ACERTA - Avaliação de Crianças em Risco de Transtorno de Aprendizagem* (Assessment of Children at Risk of Learning Disabilities) which is a multicentric research project led by Professor Augusto Buchweitz at the *Pontifícia Universidade Católica do Rio Grande do Sul* (PUCRS), Brazil. The main objective of this project is to investigate and understand early biomarkers of learning disorders like dyslexia and dyscalculia[1].

1.1 STATEMENT OF THE PURPOSE

Reading depends on efficient word recognition skills (Perfetti, 1985). Word recognition skills strongly rely on the acquisition of phonological awareness, the ability to identify and manipulate individual sounds in words (Anthony & Francis, 2005). On the other hand, reading comprehension also depends on efficient processing of semantic and syntactic information (Snowling, 2000).

Traditionally, dyslexia is associated with the phonological processing deficit as its strongest predictor (Ramus et al., 2013; 2003).

[1] More detailed information can be found on the website of the project - http://inscer.pucrs.br/projeto-acerta-2.

According to the phonological deficit theory, the processing, representation, and retrieval of phonological information are adversely affected in dyslexics (Vellutino & Fletcher, 2005). Given that mastering phonological rules, i.e., letter-sound correspondences, is crucial in the process of literacy acquisition and that dyslexics exhibit a great difficulty in acquiring these rules, the phonological deficit theory straightforwardly predicts word decoding difficulties which in turn affect both accuracy and fluency of reading and writing (Shaywitz et al., 1999).

Although the phonological processing deficit has received much support, it cannot fully account for the range of variance of dyslexics' manifestations (Castles & Coltheart, 1993; Ramus, 2001). Consequently, attention in dyslexia research has shifted from confirming the phonological processing deficit to providing evidence to deficits in other levels of language such as morphology, semantics and syntax (Bishop & Snowling, 2004; Joanisse, 2004; Rispens, 2004). The latter, i.e., syntax, is the focus of investigation in the present dissertation.

Syntax is the fundamental computational component of human language (Batterink & Neville, 2013). It refers to the ability to use a set of rules that determine how isolated words can be combined in different sequences of words in order to create meaningful sentences. Although humans' vocabulary is finite, it is possible to organize words in countless novel combinations (Fedorenko, Nieto-Castañón, & Kanwisher, 2012). Importantly, syntactic skills are a significant predictor of later development of reading skills (Cain, 2007; Tunmer & Hoover, 1992; Tunmer, Nesdale, & Wright, 1987).

Syntactic processing is a very complex cognitive task that requires a rapid and simultaneous access to syntactic rules. Studies that investigated syntactic processing in dyslexia report that dyslexics perform more poorly in comparison to non-dyslexics (e.g., Breznitz & Leikin, 2000; Leikin & Assayag-Bouskila, 2004; Robertson & Joanisse, 2010; Rüsseler, Becker, Johannes, & Münte, 2007; Wiseheart, Altmann, Park, & Lombardino, 2009).

Early accounts on syntactic processing difficulties in dyslexia have provoked a debate about their source (Bentin, Deutsch, & Liberman, 1990; Byrne, 1981; Siegel & Ryan, 1988). Research has produced results of remarkable consistency showing delayed development of syntactic abilities in children at genetic risk for dyslexia prior to formal reading instruction. Scarborough (1991) conducted a longitudinal study with kindergarteners and young pre-schoolers at risk for dyslexia. The investigation of early syntactic development revealed the existence of syntactic weakness between two and four years of age. However, by the age of five, dyslexics' difficulties in processing and producing sentences were no longer evident. Scarborough (1991) acknowledges that syntactic weakness may come out later, especially at school, where children need to perform on syntactically more demanding tasks in comparison to ordinary conversations. Two other longitudinal studies (Lyytinen et al., 2001; Wilsenach & Wijnen, 2004) report additional evidence in favor of adelayed morpho-syntactic development in pre-school children at genetic risk of dyslexia.

Studies with older dyslexic populations further confirm the existence of syntactic processing difficulties in dyslexia (Altmann, Lombardino, & Puranik, 2008; Arosio, Pagliarini, Perugini, Barbieri, & Guasti, 2016; Breznitz & Leikin, 2000; Cantiani, Lorusso, Guasti, Sabisch, & Männel, 2013; Waltzman & Cairns, 2000) and put forward the claim that dyslexics suffer from a general processing deficit that underlies difficulties in perceiving the syntactic functions of words (Breznitz & Leikin, 2000; Cantiani et al., 2013; Rüsseler et al., 2007). This view contradicts the assumption of delayed development of syntax as there are no gaps in knowledge of syntax, but there is a deficiency in integrating syntactic knowledge. Several studies have demonstrated that dyslexics are familiar with complex syntactic structures, but they fail to use them effectively in experimental contexts (Bar-Shalom, Crain, & Shankweiler, 1993; Fiorin, 2010; Wilsenach, 2006).

Controversial evidence and explanation in the literature on the syntactic processing deficit complicates matters substantially. Furthermore, studies that report this deficit in dyslexics employed different experimental designs: sentence-picture matching (Waltzman & Cairns, 2000); syntactic judgment on verb agreement (Cantiani et al., 2013; Rispens & Been, 2007; Rispens, Roeleven, & Koster, 2004); comprehension of syntactic structures such as relative clauses (Arosio et al., 2016; Bar-Shalom et al., 1993; Cardinaletti & Volpato, 2014; Leikin & Assayag-Bouskila, 2004; Mann, Shankweiler, & Smith, 1984; Rüsseler et al., 2007; Wiseheart et al., 2009), and passive sentences (Cardinaletti & Volpato, 2014; Leikin & Assayag-Bouskila, 2004; Reggiani, 2009).

In this dissertation, syntactic processing in dyslexia was investigated employing the syntactic priming paradigm. The syntactic priming paradigm can provide important insights into syntactic knowledge and the mechanisms associated with the use of this knowledge (Bock, 1986; Branigan et al., 1995). Syntactic priming is a phenomenon that occurs when prior exposure to one sentence with a certain syntactic structure (the prime) facilitates the processing of a successive sentence (the target) with the same structure (Ledoux, Traxler, & Swaab, 2007);

McDonough & Trofimovich, 2008)[2]. For example, if the participant hears a prepositional-dative sentence like *The girl showed a dress to the mother* and then s/he is asked to describe a picture using the same verb *showed*, s/he is more likely to use the same syntactic structure, i.e., a prepositional-dative structure, rather than a double-object structure (e.g. *The girl showed the mother a dress*). Since the first experimental illustration of syntactic priming effects in the choice of active versus passive structures and prepositional object versus double-object structures (Bock 1986), syntactic priming and its effects have been extensively investigated and replicated with different syntactic structures and with different languages (Mahowald, James, Futrell, & Gibson, 2016).

The facilitation effects of syntactic priming have been explained by two well-established theoretical accounts: implicit learning (Chang, Dell, & Bock, 2006; Chang, Dell, Bock, & Griffin, 2000; Jaeger & Snider, 2007) and residual activation (Pickering & Branigan, 1998). According to the first account, with syntactic priming, individuals implicitly learn the syntactic properties of a sentence structure with repetition and expect to process same or similar structure, thus leading to less effortful processing. Evidence of long lasting priming effects contribute to this account. As for the residual activation account, syntactic priming is caused by a time-limited activation of syntactic structure that decays over time rapidly. Therefore, the residual activation account does not explain evidence of long-lasting priming effects.

In language production, besides preference for the syntactic structure, the facilitation of priming effects are shown by a decrease in response latencies between the prime and the target sentences. Speakers tend to produce faster sentences with the same structure as the previous sentence in comparison to the condition with no overlap of syntactic structure (Corley & Scheepers, 2002; Segaert, Menenti, Weber, & Hagoort, 2011; Segaert, Weber, Cladder-Micus, & Hagoort, 2014; Segaert, Wheeldon, & Hagoort, 2016). In language comprehension, although syntactic priming effects have been less consistently observed, they lead to a better comprehension and a decrease in reading time (Noppeney & Price, 2004; Tooley, Traxler, & Swaab, 2009; Traxler & Tooley, 2007).

It is noteworthy that evidence of syntactic priming effects in production and comprehension has been demonstrated in studies using the functional magnetic resonance imaging (fMRI) technique (for a

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[2] Syntactic priming is also termed as structural priming in language production studies (Bock, 1986; Levelt & Kelter,1982; Pickering & Ferreira, 2008).

review, see Henson, 2003). The facilitation of processing has been associated with less neural activity (the repetition suppression effects) in relation to primed sentence structures rather than novel ones (Noppeney & Price, 2004; Segaert et al., 2011; Weber & Indefrey, 2009). The same brain regions (the left inferior frontal gyrus, left middle temporal gyrus, and bilateral supplementary motor area) are strongly related to the repetition suppression effects. Interestingly, suppressed brain activation has been reported both within and between production and comprehension (Segaert, Menenti, Weber, Petersson, & Hagoort, 2012).

In this dissertation, both the behavioral and neuronal effects of syntactic priming in dyslexia were investigated. The target population was Brazilian Portuguese dyslexic children and British English dyslexic adults. With these results, I aimed to gain a better understanding of how dyslexic children and adults process written sentences on-line and whether their processing is facilitated by syntactic priming to the same degree as in peers without dyslexia at the behavioral as well as the neuronal level.

1.2 SIGNIFICANCE OF THE RESEARCH

Many studies on syntactic priming have been concerned with the effects in a healthy population (e.g. Bock, 1986; Bock & Griffin, 2000; Levelt & Kelter, 1982; Pickering & Branigan, 1998; Segaert et al., 2011; Segaert et al., 2014). Much fewer studies have investigated syntactic priming effects in unhealthy (aphasic) population (e.g., Blumstein et al., 1991; Ferreira et al., 2008; Friederici & Kilborn, 1989). To the best of my knowledge, this dissertation is the first attempt to use the syntactic priming paradigm as a tool to tap into syntactic processing during comprehension in dyslexics.

Investigating syntactic priming effects in dyslexics can contribute to the discussion about a weak syntactic processing in this specific population. Moreover, behavioral and brain imaging data enable to verify the magnitude of syntactic priming effects, particularly to what extent dyslexics can benefit from syntactic priming. In other words, these data can foster understanding of whether dyslexics are able to adapt rapidly to or implicitly learn syntactic information.

The results of this dissertation support the account that syntactic priming reflects language learning processes and language change (Bock & Griffin, 2000; Chang et al., 2006). Specifically, the findings reveal long-lasting and cumulative syntactic priming effects for the infrequent passive structure rather than the frequent active structure in both dyslexic and non-dyslexic populations. Taking into consideration contrasting patterns of syntactic priming effects between two conditions (passives versus actives) as well as between the two populations (dyslexics versus non-dyslexics), the findings of this dissertation contribute to the discussion about sentence processing difficulties in dyslexia. Additionally, the fMRI results reported in Study II contribute to the model of language processing proposed by Hagoort (2005; 2007) by detecting brain activation in the frontal cortex regions during sentence processing in dyslexia. Importantly, the results of Study I and Study II greatly contribute to the research of dyslexia in Brazil since understanding of dyslexia in the Brazilian Portuguese speaking population is not so advanced as in the English speaking population. Finally, the results of the three studies reported in the present dissertation contribute to the field of Psycholinguistics by providing behavioral and neuroimaging data about sentence processing in the scope of dyslexia research.

1.3 ORGANIZATION OF THE DISSERTATION

In this dissertation, the main question regards sentence processing in dyslexia. To address this question, the dissertation has been organized into eight chapters. The present Chapter I introduces the general context of the topic under investigation and explains the significance of the research carried out. Chapters II reviews the literature on dyslexia from a historical perspective and attempts toward a valid definition as well as the major theoretical explanations of dyslexia. Chapter III provides explanation about the reading process at word and sentence level. In Chapter IV, the concepts of syntactic priming and the current theoretical proposals of the underlying mechanisms of syntactic priming are presented. Chapters V, VI and VII describe Study I, Study II, and Study III, respectively, which employed the syntactic priming paradigm with a dyslexic population. In each of these chapters, the research design, participants, instruments, data analyses and results are thoroughly described. Finally, Chapter VIII discusses the major findings reported in the three studies in light of the reviewed literature, presents the limitations of the dissertation, and offers suggestions for further research. In this last chapter, in addition, the educational, clinical, and social implications of the findings are discussed. References and appendices are attached to the end of the dissertation.

CHAPTER II
UNDERSTANDING DEVELOPMENTAL DYSLEXIA

Developmental dyslexia is generally defined as a failure in acquiring proper reading skills despite normal intelligence, adequate literacy instruction, and the absence of visual and hearing difficulties as well as the absence of emotional and socioeconomic difficulties (Vellutino, Fletcher, Snowling, & Scanlon, 2004). According to the commonly referenced definition proposed by the International Dyslexia Association (IDA), development dyslexia is a specific *language-based* reading disorder (Lyon, Shaywitz, & Shaywitz, 2003). This chapter provides a condensed review of literature on developmental dyslexia in order to understand what is so specific about this disorder. To this end, it seems essential to review its historical background (section 2.1). Taking into consideration a debate about the definition of dyslexia, in section 2.2, I discuss four key components proposed by Tunmer and Greaney (2010) that are crucial for a valid and operational definition of developmental dyslexia. In section 2.3, I present the major theoretical explanations of development dyslexia in order to gain a better understanding of the causes of this reading disorder. Importantly, these causal explanations are addressed in the context of Morton and Frith's (1995) model reviewed in subsection 2.3.1. Then, the following four major theories of development dyslexia are discussed: the phonological deficit theory (subsection 2.3.2), the double-deficit theory (subsection 2.3.3), the magnocellular theory (subsection 2.3.4), and the cerebellar theory (subsection 2.3.4). Finally, the last section of this chapter addresses the model of reading development proposed by Frith (1986). Understanding of the developmental progression of children's abilities in reading is crucial in order to detect in which phase of this progression a breakdown attributed to dyslexia occurs (section 2.4).

2.1 A HISTORICAL PERSPECTIVE ON DYSLEXIA

The word *dyslexia* is of Greek origin where the prefix *dys* means *difficult* and the root *lexia* means *words.* Therefore, the literal translation of dyslexia is *difficulty with words* (Payne & Turner, 1999). The German professor Rudolf Berlin, an ophthalmologist working in Stuttgart, coined this term in 1887 in order to address to a group of his six adult patients who had lost their ability to read (Shaywitz, 2003).[3] The case of these adult patients attracted the attention of Berlin who monitored them during twenty years. Based on a postmortem analysis, Berlin detected brain lesions in the left hemisphere and associated these lesions to difficulties in reading.

Earlier clinical evidence for similar behavior in reading were described by the term *word-blindness* (*Wortblindheit* in German) that was coined by another German physician Adolf Kussmaul in 1877 (Schwartz, 2010). Being interested in neurologically impaired adults with reading difficulties, he observed patients who demonstrated poor ability to recognize written words after having suffered cerebral vascular injury. Of interest is the fact that the patients` intelligence, fluency in speaking, and eyesight were not affected by any head injury they had suffered. The physician was puzzled by the fact that these abilities were intact and, in the pursuit of the problem, he continued further investigations of lesions around the left angular gyrus, a region of the brain in the parietal lobe. Based on his findings, Kussmaul concluded that it was a lesion in the left angular gyrus responsible for reading difficulties. Therefore, Kussmaul was the first scientist to associate reading disability to a lesion in this brain region.

Other clinicians such as the German physician Johann Schmidt, the British neurologist William Broadbent, and the French neurologist Joseph Dejerine also reported cases of dyslexia (Elliott & Grigorenko, 2014; Ott, 1997; Shaywitz, 2003).[4] However, it is important to bear in mind that these clinicians described atypical reading patterns in adults who had achieved normal levels of reading skills, i.e., previously they were literate, but due to brain lesions, they lost their reading skills. Today, the condition reported by Berlin, Kussmaul and other clinicians is termed *alexia* (*acquired dyslexia)*.

Alexia is a reading disorder that emerges in premorbidly literate individuals who have lost previously developed reading skills after a brain injury (Leong & Joshi, 2013). Similar atypical reading patterns are also observed in people who have never achieved the expected reading level.

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[3] The term *dyslexia* was presented first in 1887 by Professor Dr. Rudolf Berlin in his monograph *Eine besondere Art der Wortblindheit (Dyslexie)*.

[4] It is important to give special credits to Thomas Willis, an English physician and neuroanatomist, who described clinically the first case of dyslexia in his work *De Anima Brutorum* (*Of the Soul of Brutes*) in 1672 (Critchley, 1996; apud Ott, 1997).

The term *developmental dyslexi*a, or *dyslexia* applies to this condition. In light of this, the nature of reading disability in alexia and dyslexia is different (Jackson & Coltheart, 2001).

Noteworthy, there are reasons to be wary of claims that alexia is always related to adults and brain damage as its cause, while dyslexia is only encountered in school-age children (Jackson & Coltheart, 2001). Based on case studies, cumulative evidence has revealed that age and brain damage are not necessarily associated to the type of dyslexia. For example, there are cases of children who used to be normal readers and have demonstrated progress in developing reading skills, but who suddenly lost reading ability. In other words, they lost the reading competence they had achieved before. This is a case of alexia. A case of an elderly woman at the age of 80 who has always had great difficulties with reading is an example of dyslexia because she has never been a competent reader.

Additionally, brain damage is not always indicative of alexia because there are cases of alexia where brain damage is not necessarily the source of reading difficulties. Jackson and Coltheart (2001) give an example of a man who used to be a skilled reader, but one day he woke up and perceived his difficulties in reading. Neither brain abnormality, nor brain damage were later detected in such patient. Nevertheless, his case received the diagnosis of alexia. As regards dyslexia, brain abnormalities associated to defective brain maturation are central to the explanation of this reading disorder (Habib, 2000; Shaywitz et al., 2002).

The first report of developmental dyslexia entitled *A case of Congenital Word Blindness* was published by the British physician Dr. William Pringle Morgan in 1896 (Shaywitz, 2003; Snowling, 2000). In his report, Morgan described a 14-year-old boy named Percy F. as case of developmental dyslexia (Cook & Ryan, 2016). Despite being bright and intelligent, quick at games, the boy had severe difficulties in learning to read. Percy struggled with reading simple sentences making mistakes in every single word, except for articles, prepositions and conjunctions. Moreover, he made many spelling error, including in his own name writing as *Precy*. Morgan also tested his ability to read numbers and do mathematical operations like multiplication and was puzzled by the fact that the boy performed these tasks easily demonstrating no difficulty. In light of accumulated evidence, Morgan concluded that Percy's inability to learn to read was due to a congenital abnormality in the left angular gyrus since similar difficulties were observed in adults with injury in this region. [5]

With the passage of years, more cases of developmental dyslexia were reported in Europe and the United States (Elliott & Grigorenko, 2014; Shaywitz, 2003). During the 1920s one of the prominent researchers, who tried to understand the origins of this reading disorder, was the American neurologist Dr. Samuel Torrey Orton. His influential work entitled *Reading, Writing and Speech difficulties in Children* was published in 1937 (Ellis, 1993). Orton proposed a theory of cerebral dominance, suggesting that in dyslexics neither hemisphere was dominant and that would explain basic symptoms of developmental dyslexia, such as reversals of letters, syllables, and words. Even though his hypothesis was refuted, many of his observations had a profound impact on understanding dyslexia and sparkled a great deal of debate in the literature (Høien & Lundberg, 2000). One year after Orton's death in 1948, the *Orton Dyslexia Society* was founded with the mission to continue his work on the prevention, treatment, and study of this disorder[6].

As can be seen from the presented historical perspective, research on dyslexia began more than a century ago and since then important contributions have been made to dyslexia research (Jackson & Coltheart, 2001). Today, there is a general consensus that developmental dyslexia is a disorder of neurobiological origin characterized by difficulties in reading and writing skills (Cook & Ryan, 2016). With advanced neuroimaging techniques (fMRI, EEG, MEG), it as been possible to detect the neuronal abnormalities associated with this disorder. However, despite a plethora of reports with detailed descriptions of the behavioral symptoms observed in dyslexia, the definition has been subject of a debate over the last 50 years. Researchers agree that dyslexia may have several underlying causes and is generally accompanied by other developmental disorders, such as attention deficit hyperactivity disorder (ADHD) (Joshi & Aaron, 2016). The next section aims at presenting

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[5] There was another clinician who shared the credit for this first report of developmental dyslexia as he publicly presented his ideas of dyslexia in 1896. The British doctor James Kerr observed some children who had failed to learn to read and write. Similarly to the case of Percy F., those children had no other cognitive deficits. Thus, Kerr diagnosed them with congenital word-blindness (Ellis,1993; Ott, 1997).

[6] The *Orton Dyslexia Society* is the former name of the *International Dyslexia Association* or *IDA*, which is a non-profit education and advocacy organization dedicated to the issues related to dyslexia in the USA (www.interdys.org).

important characteristics of developmental dyslexia that the definition should account for.

2.2 TOWARDS A DEFINITION OF DEVELOPMENTAL DYSLEXIA

Despite years of research, there is still a considerable debate on the appropriate definition for developmental dyslexia (Castles & Coltheart, 1993; Fisher & DeFries, 2002; Fletcher, 2009; Lyon et al., 2003). Much disagreement concerns the underlying causes of developmental dyslexia (hereafter, dyslexia) which also implicates appropriate forms of assessment. Rice and Brooks (2004) reviewed over 1200 book chapters and papers and analyzed many definitions of dyslexia. The researchers distinguish two types of definitions: descriptive and explanatory (Rice & Brooks, 2004). Descriptive definitions of dyslexia are those that purely describe developmental difficulties, such as poor word decoding (reading) and encoding (spelling). This type of definition aims at facilitating the early diagnosis of dyslexia, which in turn leads to early intervention. However, descriptive definitions lack explanatory elements with respect to possible underlying causes of dyslexia. Explanatory definitions rely on explanatory theories that attempt to provide explanations for dyslexia. Thus, the definition for dyslexia remains a contentious issue among researchers and clinicians.

Tunmer and Greaney (2010) sought to contribute to this debate by providing answers to three interrelated questions: What is dyslexia? What causes it? What can be done about it? (p. 229). According to the researchers, the conceptualization of how dyslexia is defined, what causes difficulties in learning to read, and what intervention is the most effective is strongly influenced by a broader conceptualization of what reading is and how it is acquired. On the basis of the answers to the above questions, Tunmer and Greaney (2010) strongly advocate that the plausible definition of dyslexia should encompass the following four components: (1) persistent literacy learning difficulties, (2) exclusionary factors, (3) exposure to evidence-based instruction and intervention, and (4) inclusionary factors.

A definition that contains these four components is the one developed by a working group of the International Dyslexia Association (Lyon et al., 2003). Moreover, the definition of Lyon and colleagues (2003) is commonly accepted and cited in the literature of dyslexia (Elliott & Grigorenko, 2014; Fletcher, 2009; Reid et al., 2008). The updated version of the working definition of 1994 is as follows:

> Dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include difficulties in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge (Lyon et al., 2003, p. 2).

Importantly, this definition provides essential characteristics of dyslexia. In the opening sentence of the definition, Lyon and colleagues (2003) state the specificity of dyslexia towards learning skills as well as its neurobiological origin. It is noteworthy that this definition also goes beyond the established view of dyslexia as single word decoding difficulties. Decoding abilities, for instance, of pseudowords, and poor spelling are also considered as a manifestation of dyslexia. [7] Additionally, the definition presents secondary consequences of dyslexia, such as reading comprehension difficulties and reduced reading experience. These consequences, in turn, may lead to a limited growth in vocabulary and background knowledge. The definition of Lyon and colleagues (2003) also includes the core causal explanation of dyslexia, the phonological processing deficit, which is not related to intelligence and classroom instruction.

It is important to state that traditionally, clinicians have identified dyslexic individuals with the help of standardized tests, which measure intelligence and cognitive abilities in order to attest that literacy-learning difficulties of dyslexics are not directly caused by low intelligence.[8] As a consequence, many definitions of dyslexia hold with the idea of the

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[7] Here, a distinction needs to be made between pseudowords and non-words, which are also frequently employed in the lexical decision task or the word naming task used to assess phonological processing abilities (Thomson, Crewther, & Crewther, 2006). Pseudowords are pronounceable strings of letters which resemble real words, but have no meaning (e.g., *wird*), whereas non-words are non-pronounceable strings of letters formed in a random order (e.g., *dsrte*).

[8] Tests like the Wechsler Adult Intelligence Scale (WAIS) and Wechsler Intelligence Scale for Children (WISC) are used to measure reasoning skills and problem-solving abilities in adults and children, respectively.

discrepancy-based criterion, i.e., the discrepancy between mental age measured by an intelligence quotient (IQ) and reading age measure by standardized tests of reading accuracy and comprehension in comparison to chronological age (Bishop & Snowling, 2004; Fletcher, 2009; Lyon et al., 2003; Ramus, 2003). The examples of discrepancy-based definitions are the ones proposed by two influential diagnostic systems, the ICD-10 Classification of Mental and Behavioural Disorders (World Health Organization-WHO, 1993)[9] and the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV) (American Psychiatric Association, 1994; as cited in Lyon, 1995). [10]

Taken together, the definition of Lyon and colleagues (2003) is very straightforward. In the present dissertation, I adopt the definition of Lyon and colleagues (2003) because it can be applied to the three studies reported here that which investigated dyslexics' abilities beyond single word reading. In Study I, dyslexics' syntactic processing was measured by means of the sentence-reading task. Additionally to the sentence reading task, in Studies II and III language skills and intelligence tests were administered in order to establish the discrepancy between verbal and non-verbal abilities.

Having defined the conceptualization of dyslexia for this dissertation, it seems commonsensical to discuss the etiology of dyslexia. Notably, there is no single theory that describes and explains all manifestations of dyslexia. In the attempt to a plausible explanation of dyslexia`s manifestations, several theoretical explanations have been proposed based on empirical evidence. The next subsection presents an overview of the most influential theoretical explanations of dyslexia.

2.3 THEORETICAL EXPLANATIONS OF DEVELOPMENTAL DYSLEXIA

The definition and explanation of dyslexia have become a matter of debate, where the nature and features of this disorder are central (Elliott & Grigorenko, 2014). In order to achieve a better understanding of this disorder, the first step is to distinguish between the different levels of existing explanations for dyslexia. Morton and Frith (1995) have proposed a causal model, which clearly distinguishes the three major

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[9] Dyslexia as specific reading disorder is coded F81.0 as a subtype of Specific developmental disorders of scholastic skills (code F81) in ICD-10.

[10] Dyslexia as reading disorder is coded 315.00 as a subtype of learning disorders in the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV).

levels of explanation: biological, cognitive, and behavioral. By providing full causal explanation for this disorder, this causal model has become widely acknowledged and commonly referenced (Frederickson, 2009; 2010; Pavey, 2007; Snowling, 2000). The present section describes this causal model as well as it further discusses the current explanatory theories of dyslexia in the context of the model. The choice to address theories of dyslexia by means of Morton and Frith`s (1995) model is attributed to the fact that the model brings together different levels of explanation and provides explicit diagrams of theoretical explanations, which contribute to a thorough understanding of dyslexia.

2.3.1 A causal model of developmental disorders

The lack of an agreed definition as well as the debate over the underlying causes of dyslexia motivated two developmental psychologists, John Morton and Uta Frith, to think about a neutral framework that would compare different theories of development disorders and find the common ground between them (Morton & Frith, 1995). The framework proposed by Morton and Frith (1995) incorporates three levels of explanation: the biological level, the cognitive level, and the behavioral level. According to Morton and Frith (1995), all three levels are important as well as they complement each other. Additionally, the researchers include environmental factors in the framework as they may have an impact on one or all of these levels. In Figure 2.1, the rudiments of this framework are presented.

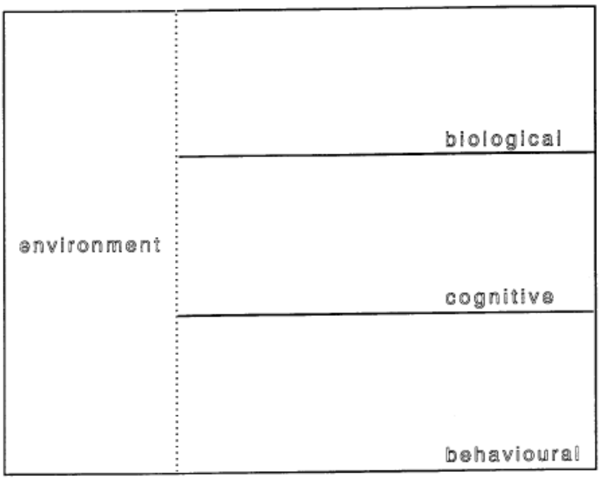

Figure 2.1. The three-level framework (Frith, 1999, p.193).

It is well assumed that clinicians diagnose dyslexia based on specific behavioral manifestations. Morton and Frith (1995) suggest that all behavioral manifestations of dyslexia should be associated with the behavioral level of the framework. Therefore, evidence regarding what dyslexics can do and cannot do in relation to language, especially related to reading and writing, should be described in the space labeled *behavioral* of the framework.

Given that dyslexia is a disorder of neurobiological origin, Morton and Frith (1995) give a special attention to the differences in the neurobiological substrates between dyslexic and typically developing individuals. Being the deepest level of explanation of dyslexia, the biological level includes contributions from genetic and brain imaging research. There has been growing evidence from molecular genetics that a number of inherited genes may contribute to the development of dyslexia, for example, DYX1C1, KIAA0319, DCDC2 and ROBO1 (Fisher & DeFries, 2002; Fisher & Francks, 2006). Additionally, dyslexia is a congenital neurobiological disorder caused by abnormal brain structure, in particular abnormal magnocellular pathways and abnormal cerebellum (Shastry, 2007). These brain abnormalities are associated with explanation at the biological level of the framework.

According to Morton and Frith (1995), valuable contributions to the understanding of dyslexia come from the cognitive level where causes of dyslexia are associated with deficient information-processing mechanisms. Current theoretical explanations of dyslexia at the cognitive level include deficits in short-term or working memory, phonological awareness, incomplete automatization, and slow processing (Reid, Soler, & Wearmouth, 2003). For instance, there is a general consensus about the phonological processing deficit (Ramus et al., 2003). The phonological deficit theory is discussed in more details in subsection 2.3.2.

Overall, Morton and Frith (1995) highlight the importance of each level and environment factors when analyzing different explanatory perspectives on dyslexia. The researchers claim that investigating causes of dyslexia at the proposed three levels as well as the causal links between these levels will be helpful in understanding and explaining this disorder. Additionally, this framework integrates the potentially disparate theoretical accounts of dyslexia, which may seem to be in conflict with each other at first sight. An example of this is an integration of two commonly referenced theories that explain dyslexia as a cause of a phonological deficit and a magnocellular deficit, respectively. As previously stated, the phonological deficit theory is associated with the cognitive level of explanation where a deficit in phonological processing is the source of reading difficulties among dyslexics. The magnocellular deficit theory assumes that there is an abnormality in the magnocellular system of dyslexics which causes reading difficulties. This theory is attributed to the biological level of explanation and is described in detail in subsection 2.3.4. From the perspective of Morton and Frith's (1995) model, both theories are compatible with each other, and not mutually exclusive. The researchers claim that theoretical explanations should not be confined to a particular level of the framework. They may originate at one level and extend to others as shown in Figure 2.2.

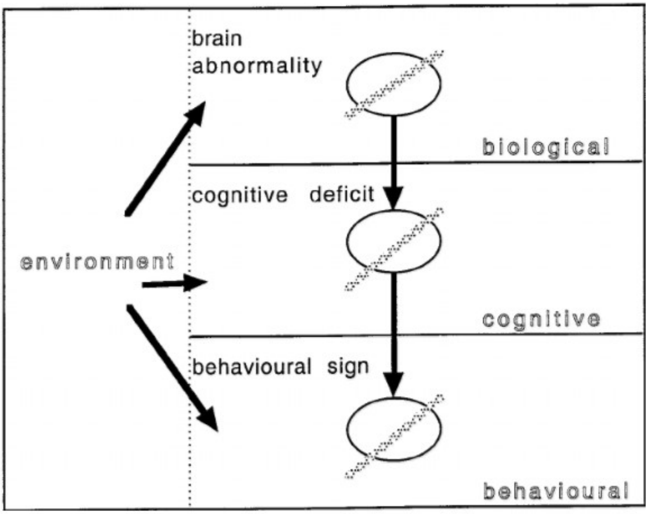

Figure 2.2. A causal model of a developmental disorder of neurocognitive origin (Frith, 1999, p.196).

Figure 2.2 illustrates a diagram with the hypothetical causal relationship across the three levels of explanation. The crossed-out fields indicate possible deficits at each level. With the help of arrows, the diagram shows a top-down direction from the biological level through the cognitive level to the behavioral level to indicate causal links between the levels. In accord with these causal links, dyslexia can be defined as a developmental disorder caused by a brain abnormality, which in turn provokes a cognitive deficit, and the latter brings out certain behavioral manifestations.

Importantly, a bottom-up causal direction is also possible, i.e., from the behavioral level through the cognitive level to the biological level (Hulme & Snowling, 2013). As Hulme and Snowling (2013) claim, changes at the behavioral level may also have an impact at the cognitive level, and changes at the cognitive level may result into changes in the underlying brain mechanisms. For instance, remedial teaching as one of the environmental factors may influence behavior signs, which may induce changes in the cognitive system, which in turn may lead to modifications in brain structure or function. Besides remediation, there is a wide range of environmental factors, which may generate a positive as well as a negative impact for each level, such as maltreatment, socio-economic status, and cultural attitudes.

Taking into account a range of causal explanations at the biological and cognitive levels, Morton and Frith's (1995) emphasize the importance to consider not only behavioral manifestations for a diagnosis of dyslexia, such as poor reading accuracy and speed, but also evidence of a brain abnormality and cognitive deficits. By criticizing purely behavioral definitions, Frith (1999) presents two extreme cases which illustrate the confusion that is common between dyslexia and reading difficulties. These two cases are discussed in terms of the causal model of Morton and Frith (1995).

The first case regards a dyslexic individual who gains high scores on literacy assessment tests. In general terms, this individual does not manifest behavioral signs typical for dyslexics. Figure 2.3 shows that dyslexic's successful performance on tests might be attributed to effective remedial teaching. However, the underlying causes have persisted at both the biological and cognitive levels. This case illustrates that deficits at these levels request other evidence to elicit slow and inaccurate performance, such as oral reading, and not only reading for general comprehension.

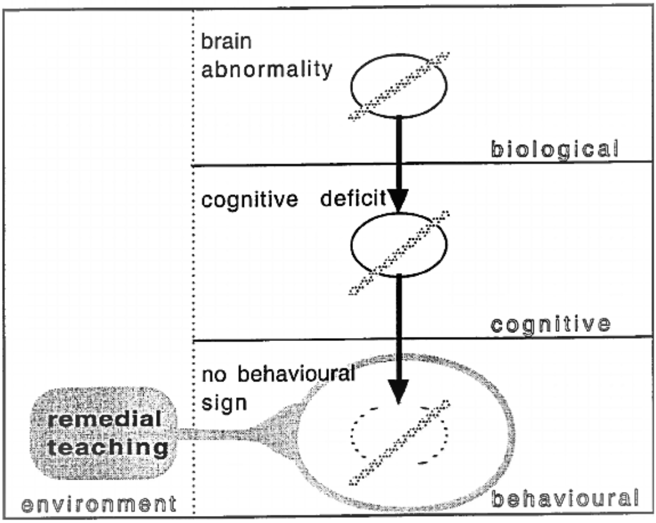

Figure 2.3. A causal model of compensation in developmental disorders (Frith, 1999, p. 197).

The second case described by Frith (1999) is an individual with reading difficulties. Although s/he had reading difficulties, no other signs of deficits at the biological and cognitive level were detected. Figure 2.4 illustrates this case by providing causal links which may explain the observed reading difficulties. As can be seen, difficulties at the behavioral level cannot always be associated with a brain abnormality or a cognitive deficit. Indeed, there are other causes of environmental origin which may explain poor reading performance, such as a disturbed socio-cultural context. For example, discomfort in the classroom due to the unfavorable relationship with the teacher or classmates may contribute to the development of reading difficulties.

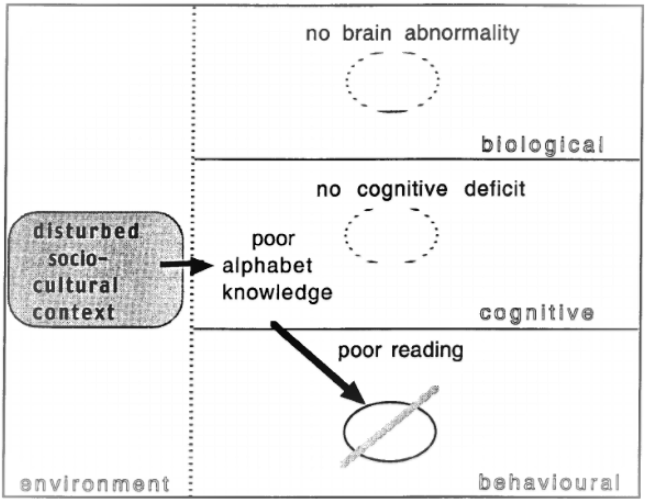

Figure 2.4. A causal model of poor reading: not dyslexia (Frith,1999, p.198).

To conclude, the causal model proposed by Morton and Frith (1995) explains the dyslexia phenomenon in terms of three related levels: biological, cognitive, and behavioral. According to Morton and Frith (1995), contemporary theories of dyslexia may be modeled in the three-level framework. Therefore, the following subsections are devoted to these theories which explain neuro-cognitive causes of dyslexia.

2.3.2 The phonological deficit theory

Over the last 40 years, research in dyslexia has accumulated a wide range of empirical evidence in support of both the phonological deficit in dyslexia and effective intervention programs based on phonological training (Lyon et al., 2003; Fawcett & Nicolson, 1995; Nicolson & Fawcett, 1995; Joanisse et al., 2000; Pennington, 1990; Ramus & Szenkovits, 2008; Ramus, 2003; Snowling, 1995). The description of the phonological processing deficit comprises three main components: poor phonological awareness, poor verbal short-term memory and slow lexical retrieval (Ramus, 2004).

Phonological processing difficulties in dyslexics are well-documented (Ramus, 2003; Snowling, 2000; Vellutino et al., 2004). These difficulties are especially detectable in tasks requiring phonological awareness, i.e., the ability to manipulate speech sounds (phonemes) and their combinations (syllables) consciously (Ramus, 2004). Having poor phonological awareness, dyslexic individuals have difficulties in performing tasks such as syllable counting, phoneme deletion or substitution. A deficit in phonological processing manifests in tasks which require memory for phonological sequences (Ramus, 2004). Dyslexics demonstrate severe difficulties in tasks aimed at remembering sequences of sounds or letters or repeating non-words. The phonological processing deficit also affects lexical retrieval, which is an undeniable skill for reading (Ramus, 2004). Dyslexics are seriously challenged by tasks which require the ability to name aloud letters or objects rapidly. According to Ramus (2004), phonological awareness, verbal short-term memory, and lexical retrieval are responsible for the representation, storage, and retrieval of linguistic material, i.e., information processing at the cognitive level. Failures in one or all of these abilities may explain a variety of behavioral manifestations in dyslexia.

Figure 2.5 shows a subset of behavioral signs of a phonological deficit in the context of a causal model of Morton and Frith (1995). Based on findings of post-mortem anatomical and brain imaging studies, the brain basis of the phonological deficit is associated with an abnormality in the left-hemisphere language system (Démonet, Taylor, & Chaix, 2004). In particular, there are abnormal responses in the left inferior frontal region with increased activation, the left parietal-temporal regions and the left inferior temporal-occipital regions with reduced activation during both phonological and reading tasks (Démonet et al., 2004; Hoeft et al., 2006; Shaywitz & Shaywitz, 2005). Importantly, difficulties in phonological processing are neither related to auditory impairments, where an individual cannot reproduce a sound due to inadequate hearing, nor to visual impairments caused by physical difficulties with the eyes.

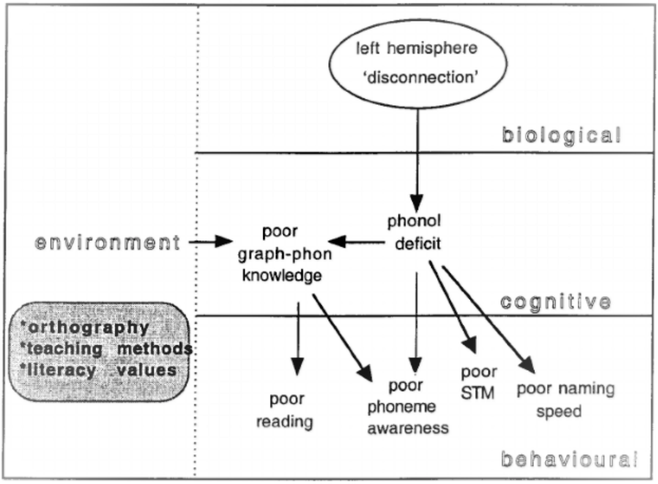

Figure 2.5. A causal model of dyslexia as a result of a phonological deficit (Frith, 1999, p.203).

The diagram in Figure 2.5 also shows the influence of several environmental factors, such as orthography, teaching methods, literacy values, which may have a strong impact on the acquisition of grapheme-phoneme knowledge. For instance, the type of orthography may influence the developmental progress of children to learn to read (Vellutino et al., 2004). Languages with opaque orthographies, i.e., languages with no consistent relationship between graphemes and phonemes, such as French, present a significantly greater challenge to many beginning learners than languages with transparent orthographies, i.e., languages with consistent relationship between graphemes and phonemes, such as German or Italian. Moreover, teaching methods play an important role in building phonological skills as well as societal values strongly influence literacy acquisition (reading and writing).

The phonological deficit theory has become the most commonly referenced theoretical explanation of dyslexia. Although this theory provides a reasonable and coherent explanation of dyslexia, controversy still exists because not all dyslexics demonstrate difficulties in phonological processing. The main criticism of the phonological deficit theory is that it typifies the idea of a phonological deficit as exclusive in nature. In the next subsection, the role of two distinct cognitive deficits responsible for information processing, i.e., a phonological deficit and a rapid-naming deficit, is addressed in terms of the double-deficit theory.

2.3.3 The double-deficit theory

A number of scholars defend the notion that dyslexics' difficulties are not exclusively or mainly associated with a deficit in phonological processing (Lovett, Steinbach, & Frijters, 2000; Wimmer, Mayringer, & Landerl, 2000; Wolf & Bowers, 2000). Therefore, the double-deficit theory, which is an extension of the dominant phonological deficit theory, has been proposed (Wolf & Bowers, 2000). The double-deficit theory recognizes the role of phonological processing skills for reading development. However, according to this theory, dyslexics have a deficit in rapid serial/automatized naming (RAN), an equally important skill for reading development. The double-deficit theory proposes that dyslexic individuals have a single deficit in one of these skills or the double deficit in both skills.

Taking into account the results of extensive investigations, Wolf and Bowers (2000) claim the existence of three subtypes of dyslexic readers: the first subtype exhibiting a single deficit in phonological skills, but intact naming speed, the second subtype exhibiting a single naming-speed deficit, but intact phonological skills, and the third subtype exhibiting a double deficit, when both phonological and rapid-naming skills are impaired. A phonological deficit has a strong relationship with decoding accuracy, whereas a naming-speed deficit is strongly associated with reading fluency.

The important implication of this theory is that individuals with a single naming-speed deficit require adequate intervention and not the one solely based on the training of phonological skills. In line with this, training phonological skills may not be so effective for languages with transparent orthographies. For instance, in languages like Italian and German where skills in phonological processing play a less important role, naming speed becomes a powerful predictor of reading performance (Nijakowska, 2010). Noteworthy, individuals with a double deficit, i.e., with difficulties in both reading accuracy and speed, are the most severely impaired subtype, thus suggesting a more intensive intervention based on training both phonological and rapid-naming skills.

The double-deficit theory has been intensely investigated by providing a substantial body of evidence for its main assumptions (Lovett et al., 2000; Wolf, Bowers, & Biddle, 2000). For instance, Lovett and colleagues (2000) conducted a study with 166 children with severe reading disabilities with age ranging from 7 to 13 years old. The researchers aimed at categorizing children's difficulties according to the presence or absence of a phonological and naming-speed deficit (Lovett et al., 2000). The data of 84% of the sample (140 children) were submitted to further analysis revealing that 54% of the sample demonstrated a double deficit, 24% had a single naming-speed deficit and 22% had a phonological deficit. It should be noted that children with the double deficit were more severely impaired in comparison to children with single deficits. Based on evidence in support to a double deficit in dyslexic individuals, Wolf and colleagues (2000) argue that a phonological deficit is not the only core deficit in dyslexia. There is a second core naming speed deficit, which influences reading performance in terms of fluency. According to the researchers, intervention programs for dyslexics should include practices on both skills (Wolf et al., 2000).

In hindsight, the two theories of dyslexia presented above have a causal explanation at the cognitive level. According to Morton and Frith (1995), the cognitive level constitutes a crucial link between the biological and behavior levels, with underlying causes of cognitive deficits arising from structural abnormalities of the brain. Owing to the assumption of a causal model of Morton and Frith (1995), behavioral manifestations of language processing difficulties in dyslexia are caused by brain abnormalities. Therefore, the dyslexic brain has attracted researchers' attention as the likely source of language processing difficulties (Galaburda, 2005; Habib, 2000; Shaywitz et al., 2002; Shaywitz & Shaywitz, 2005).

Before discussing the theoretical explanations of dyslexia in relation to brain abnormalities, it is important to give credits to the earliest investigations of the dyslexic brain. The American neurologist Norman Geschwind had an idea to undertake a neuroanatomical analysis of dyslexic brains and compare them to the ones of non-dyslexics (Galaburda, 2005). As stated in the review article of Galaburda (2005), Geschwind confirmed brain asymmetry in dyslexics and explained this evidence as insufficient amount of brain tissues in the left hemisphere, which is heavily involved in language processing. In the brain of typically developing individuals, there is a distinct dominance of the left hemisphere (left hemisphere is bigger) over the right hemisphere in relation to its size (Galaburda, 2005). On the contrary, the dyslexic brain has a reversed asymmetry, i.e., the right hemisphere is bigger than the left one, or both hemispheres are symmetrical. Additionally, Geschwind hypothesized that an insufficiency of brain tissues in the left hemisphere could be triggered by an improper development of language regions in fetus, particularly during the migration of young neurons to their final destination in the brain.

Geschwind`s ideas were further investigated by Galaburda and his group of researchers (Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985), who were among the first interested in the brain organization of dyslexic individuals. Galaburda's group observed neural abnormalities (ectopias), i.e., dismigration and disorganization of the neurons, in many areas of dyslexic cerebral cortex, especially in the left hemisphere language areas. A plausible account of ectopias in combination with a phonological deficit is that anomalous neural development is more pronounced in the language areas of the left hemisphere, particularly the perisylvian region.

Interesting findings were revealed comparing four male and three female dyslexic brains (Galaburda et al., 1985; Humphreys, Kaufmann, & Galaburda, 1990). The number of participants was limited as these were two postmortem investigations. The researchers concluded that the location of neural abnormalities was different in males and females. In dyslexic males, the brain showed symmetry of the planum temporale and predominantly left-sided microscopic abnormalities in the cerebral cortex.[11] Regarding the female dyslexic brain, the researchers also concluded that the brain had the symmetrical planum temporale, but there were fewer abnormalities, which varied in location, when compared to the brain of male dyslexics (Humphreys et al., 1990). It is important to state that the planum temporale in typically developing individuals has a leftward asymmetry with greater size (Bloom, Garcia-Barrera, Miller, Miller, & Hynd, 2013).

During the last decade brain imaging techniques, such as Magnetoencephalography (MEG), and functional Magnetic Resonance Imaging (fMRI), have been extensively used to investigate dyslexia (Baillieux et al., 2009; Beneventi, TøNnessen, Ersland, & Hugdahl, 2010; Richards & Berninger, 2008; Rimrodt et al., 2009). With the help of these techniques, researchers have had the opportunity to observe brain activity during online processing tasks. Brain imaging data have received targeted attention in order to enhance understanding of dyslexia and two theoretical explanations have emerged: the magnocellular deficit theory and the cerebellar deficit theory. These two theories are discussed next.

[11] The planum temporal is located within Wernicke's area and is strongly associated with auditory and phonological processing as well as language in general (Bloom, Garcia-Barrera, Miller, Miller, & Hynd, 2013).

2.3.4 The magnocellular deficit theory

Reading involves fast and accurate visual identification of letters and words. According to Stein and colleagues, the visual system is crucial to reading and dyslexia is the result of abnormalities in the neural pathways of this system (Stein, 2001; Stein, Talcott, & Walsh, 2000). The visual system is divided into two distinct pathways: magnocellular and parvocellular (Greatrex & Drasdo, 1995). Each pathway has different functions and properties. The magnocellular pathway is responsible for the fast input transmission from the retina to the occipital and parietal brain regions and the parvocellular pathway processes the details of this input.

According to the magnocellular deficit theory, poor reading performance of dyslexics is due to abnormally reduced sensitivity in the magnocellular system (Livingstone, Rosen, Drislane, & Galaburda, 1991; Lovegrove, Bowling, Badcock, & Blackwood, 1980; Skottun, 2000; Stein et al., 2000). In particular, the visual sensory abnormalities are the result of magnocells shrinkage (magnocells are about 27% smaller in dyslexics) and disorganization in lateral geniculate nucleus, whereas the parvocells are intact (Greatrex & Drasdo, 1995; Hutzler *et al.*, 2006; Livingstone *et al.,* 1991). A reduced ability to detect visual stimuli rapidly can result in visual stress. Thus, dyslexics manifest a variety of symptoms of visual stress, such as headaches, eye strain, poor concentration, difficulty to remember what has been read, omission of words and lines when reading (Kelly & Phillips, 2016).

Figure 2.6 illustrates a causal connection between abnormalities in the magnocellular system and behavioral signs of dyslexia (Frith, 1999). Fluency and accuracy in reading are dependent on fast and accurate processing of both visual and auditory information. As Stein (2001) proposes, dyslexics have lower sensitivity to both visual and auditory stimuli in comparison to typically developing individuals. At the cognitive level, difficulties of dyslexics are attributed to a general temporal processing dysfunction. As a consequence, this dysfunction leads to a visual magnocellular deficit and an auditory deficit. The temporal auditory deficit is thought to cause a deficit in phonological processing. At the behavioral level, the visual magnocellular deficit explains dyslexics` difficulties with tasks, which require the perception of motion. Difficulties associated with the temporal auditory deficit are poor tone discrimination, poor speech development, and poor reading.

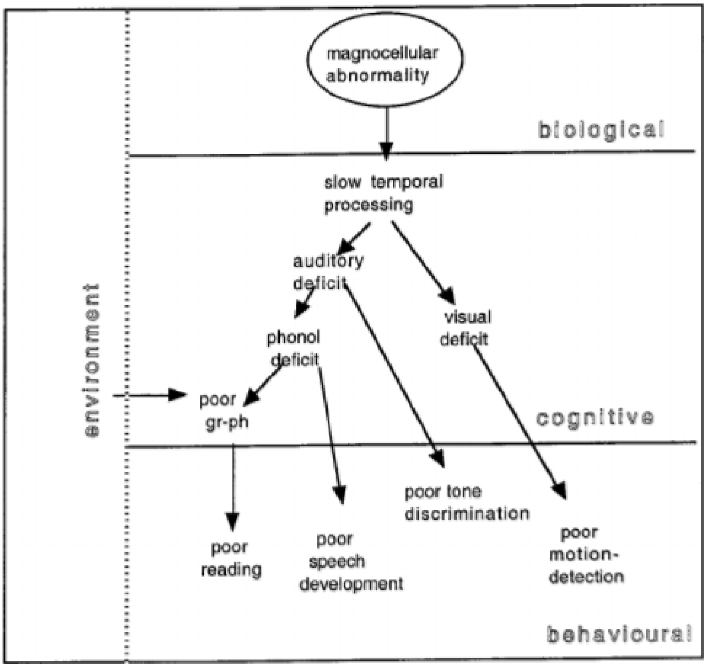

Figure 2.6. A causal model of dyslexia as a result of a magnocellular abnormality (Frith,1999, p.205).

In addition to the visual and auditory deficits, the magnocellular deficit theory also explains the cerebellar deficit in dyslexics (Stein, 2001). Taking into account that the cerebellum receives information from the magnocellular system, the cerebellum is also affected by a more general magnocellular dysfunction. Thus, the cerebellar deficit theory has been proposed. This theory is reviewed in the next subsection.

2.3.5 The cerebellar deficit theory

The cerebellum has been traditionally viewed as the area involved in learning and the automatization of motor skills (Nicolson & Fawcett, 2008; Stein & Glickstein, 1992). However, during the last two decades the assumption that the cerebellum might be involved in cognitive skills, particularly in language processing, emerged (Fabbro, Moretti, & Bava, 2000; Justus & Ivry, 2001; Marien, Engelborghs, Fabbro, & De Deyn, 2001). Recent brain imaging studies provided valuable contributions for this evidence by detecting activation in the cerebellum during reading tasks (Carreiras, Mechelli, Estévez, & Price, 2007; Fulbright et al., 1999; Joubert et al., 2004; McDermott, Petersen, Watson, & Ojemann, 2003; Mechelli, Gorno-Tempini, & Price, 2003).

Based on the converging evidence for cerebellar dysfunction in dyslexics, Nicolson and Fawcett (2010) proposed the cerebellar deficit theory. According to Nicolson and Fawcett (2010), dyslexic individuals fail to develop automaticity in reading skills due to a dysfunction in the cerebellum. In particular, this dysfunction was reported in brain imaging studies as a reduced activation in the right cerebellum confirming that the magnocellular deficit also affects the cerebellum (Nicolson et al., 1999; Rae et al., 1998).

Figure 2.7 shows a causal connection between cerebellar abnormality and behavioral signs of dyslexia (Frith, 1999). An impaired cerebellum implies a temporal processing deficit at the cognitive level. Slower-than-normal temporal processing is associated with deficits in phonological and motor skills. At the behavioral level, the motor control deficit explains poor naming speed, poor time estimation, poor motor development, and poor balance. Difficulties associated with the phonological deficit are poor naming speed and poor reading.

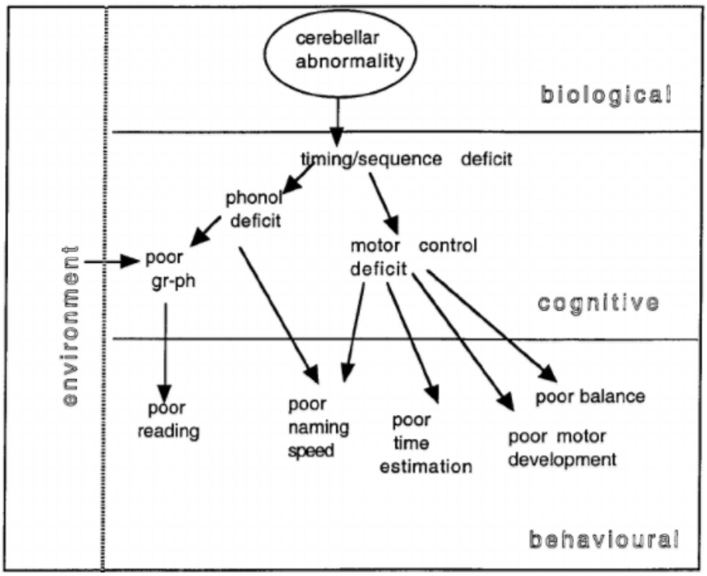

Figure 2.7. A causal model of dyslexia as a result of a cerebellar abnormality (Frith, 1999, p.206).

Altogether, the cerebellar deficit theory treats dyslexia as a general learning disability (Nicolson, Fawcett, & Dean, 1995; Nicolson, Fawcett, & Dean, 2001). Difficulties in reading and writing are caused by a deficit in the cerebellum which is responsible for skill automatization. Therefore, the supporters of the cerebellar theory claim that difficulties in phonological processing and motor skills experienced by dyslexics should be attributed to a dysfunction in the cerebellum (Fawcett & Nicolson, 1994, 1995b; Nicolson, Fawcett, & Dean, 1995; Nicolson, 1994). The cerebellar deficit theory as well as the magnocellular deficit theory explain the phonological deficit as caused by a more general temporal processing deficit, thus suggesting that intervention at the sensory level can also be helpful (Tallal et al., 1996).

Having presented the causal explanations of dyslexia, I turn now to a review of a model that explains how reading is developed in the next section. The model proposed by Frith (1986) describes the developmental progression of children’s abilities in reading and also accounts for a breakdown in this progression, which is associated with dyslexia.

2.4 TYPICAL READING DEVELOPMENT

There has been considerable interest in the reading literature about children`s progress in reading development (Elbro, 1996; Kirby, Desrochers, Roth, & Lai, 2008; Kirby et al., 2008; Nation & Snowling, 1998) and a developmental model of reading can serve for many purposes. First, a developmental model can inform about crucial abilities for reading such as decoding as well as explain the developmental progression of these abilities. Moreover, a developmental model can establish the relation between reading and cognitive abilities involved in this process. An example of such model is the model of reading development proposed by Uta Frith (1986) that is currently one of the most prominent and influential models of literacy development (Gathercole & Baddeley, 2014).

The model of reading development takes into account Frith`s research on and practice with children learning to read (Nunes & Bryant, 2013). Although it was proposed about 30 years ago, this model is widely accepted and commonly referenced by many scholars and still is considered applicable today (Adelman, 2012; Beaton, 2004; Hulme & Snowling, 2013). The model describes how typically developing reading abilities change and progress while children learn to read an alphabetic orthography such as English. According to the model, in order to reach success in reading, children should go through three phases: logographic, alphabetic, and orthographic (Frith, 1986).

During the logographic phase, children`s earliest attempts to read take place. However, these attempts do not involve a phonological strategy, since letter sequence is neglected, and these attempts are based on a purely visual strategy. Children recognize familiar words relying on highly distinctive visual cues such as size, shape, and length. In other words, children memorize words as visual entities, called logographs. Using this visual strategy, children are able to *read* or perceive words that are significant to them and are stored in their limited vocabulary. For instance, children recognize their own names, names of shops, and common signs. However, the strategy is not always reliable and, because it is not generative, it will not help them read unfamiliar words later. At this early phase of literacy development, children are not aware of the alphabetic principle, i.e., understanding that individual graphemes and their combinations correspond to certain sounds. The chronological age of children associated with this phase may vary from 3 to 5 years old (Bielby, 1999).

Having quite good experience with the visual forms of words, children`s visual discrimination abilities become more refined. It is in the second phase – the alphabetic phase that children develop the notion about the alphabetic principle. Unlike the first phase, the alphabetic strategy does not usually develop spontaneously. Children need to be exposed to some kind of formal instruction from more competent readers like parents, relatives, and teachers who can explain to them the grapheme-to-phoneme conversion rules. This input motivates children to analyze the relationship between graphemes and sounds in spoken and written words. The chronological age of children attributed to this phase may vary from 5 to 7 years old (Bielby, 1999).

The alphabetic phase plays a crucial role in the development of the subsequent orthographic strategy. In the orthographic phase, children develop the orthographic strategy, which enables to recognize words automatically and access their meaning immediately from the lexical memory. Word recognition and retrieval occur without much effort because children are able to break down words into orthographic segments automatically without grapheme-to-phoneme conversion, i.e., without sounding out each grapheme as in the alphabetic phase. The orthographic segments correspond to morphemes that are stored in memory. The analysis of words into orthographic segments takes place much faster than the phonological analysis. Frequent words are decoded and read much faster than infrequent ones. The chronological age of children attributed to this phase may vary from 7 to 9 years old (Bielby, 1999).

According to Frith (1986), typical literacy acquisition is characterized by the progression in each phase and the development of each strategy in the above mentioned sequence. The progress and change from one phase to the next one are not random; they are the consequence of biological (maturation) and cultural (teaching) influence. The expected outcome of this sequential development is a competent reader who demonstrates fluency and accuracy in reading. Importantly, this fixed sequential development is not restricted to the use of one strategy independently and once at a time. Sometimes children may employ two different strategies at the same time, in particular when they still do not have a full control of a new strategy and they use the previous strategy on their way to adapt to a new condition.

Another relevant issue that Frith (1986) raises in her model of reading development is that, over the course of learning, children do not always demonstrate gradual improvement in reading. At any moment of their reading development, children may have a decline in performance because the transition from one phase to another implies the acquisition of a new strategy and its integration with the already acquired strategy. The transition through phases is very sensitive and delicate and may be associated with either breakthrough or breakdown. According to Whitebread (2002), the advantage of this model is that the defined phases are quite useful and practical for instructors because they can monitor the progress made by children at a particular phase and identify whether there is some nonconformity. Additionally, the role of instructors is attributed to observation and identification of a decline in the progression through any phase and investigation of whether this decline is temporal or long lasting with the aim of providing early intervention.

Although the model proposed by Frith (1986) has particular authority in the literature on reading development, the model has also received criticism (Beech, 2005; Graham & Kelly, 2012). The main criticism comes from Ehri’s paper (Ehri, 1995) and is about an inadequate definition of the phases in the model proposed by Frith (1986). According to Ehri (1995), the concept of alphabetic processing is crucial to the definition of the developmental phases. Therefore, Ehri (1995) proposes a new model of reading development, but in this model, there are four phases: pre-alphabetic, partial alphabetic, full alphabetic and consolidated alphabetic. The pre-alphabetic phases is equivalent to Frith`s logographic phase. Frith`s (1986) alphabetic phase is divided into two: partial and full. According to Ehri (1995), the difference between these two phases lies in the ability to map graphemes to phonemes where in the partial alphabetic phase this ability is initial, and in the full alphabetic phase, this ability is fully developed. Despite the criticism of Ehri (1995), the model of Frith (1986) is currently one of the most influential developmental models of reading (Gathercole & Baddeley, 2014). In addition, the model of Frith (1986) has also been adopted to explain developmental disorders of reading like dyslexia (Høien & Sundberg, 2000; Mortimore & Dupree, 2008; Ưodej, 2016).

The idea that reading strategies are acquired at different time courses and in a fixed and continuous sequence enables the identification of developmental failure within one of these strategies. According to Frith (1986), the failure may be observed at different phases and the type of developmental disorder will depend on where exactly the failure occurs. It is reasonable to suggest that in the presence of a failure, the child tries to develop some compensatory strategies. If the child faces difficulties at one particular phase, the child may over-develop a previously acquired strategy in order to compensate these difficulties or s/he may simulate the use of a necessary strategy for a certain performance. Under the last presupposition, a simulated behavior like guessing words from the context is easily detectable because it requires more time and, hence, reduces fluency, accuracy, prosody, and also comprehension (Mather & Wendling, 2011). A failure in developing a new strategy should receive a parsimonious explanation because not all children may advance from one phase to the following one at the same or similar pace. Noteworthy, this temporal developmental delay should not be considered a developmental disorder.

When comparing developmental delay and developmental disorder, Frith (1986) argues that the crucial difference is about the course of time of children`s difficulties. In the first condition, the strategy is acquired slowly and difficulties are overcome by the end of each phase, whereas in the second condition, despite developing a compensatory strategy, difficulties persist. An example of the second condition is the case of successful dyslexics who manage to develop good reading abilities after having been exposed to effective intervention and training, but who still need to make greater effort while reading in comparison to typical readers (Frith, 1999). For this reason, dyslexia must be defined in terms of developmental disorder and not in terms of developmental delay due to the evidence that in developmental delay, the difficulty is no longer detectable in the following phase (Frith, 1999).

Additionally, Frith (1986) also claims that the gravity of a reading disorder depends on where (which developmental phase) a failure occurs, i.e., the later the failure the less severe the disorder. Moreover, Frith (1986) states that it is not possible to fail at one phase and succeed in the next phase. For instance, the child cannot learn the orthographic strategy if s/he has failed the previous strategy, i.e., the alphabetic strategy which serves as the basis for the next one. According to Frith (1986), a failure in acquiring the alphabetic strategy results in dyslexia. The researcher also explains that dyslexic individuals are able to master the logographic strategy, but there is a failure to develop the alphabetic strategy where the grapheme-to-phoneme correspondence rules are at stake. In other words, dyslexics cannot make progress beyond the logographic phase because they cannot grasp the alphabetic grapheme-to-phoneme associations. In a similar vein, they also face great difficulty to move on to the orthographic phase where fluency in reading is mastered because they have not succeeded in the previous phase.

In summary, this chapter introduced dyslexia as a neurobiological disorder that was first clinically described in 1672 by an English physician and neuroanatomist Thomas Willis. Dyslexia has attracted much attention of scholars due to its puzzling behavior manifestations. Although dyslexia has been studied consistently during the last century, there is still no consensus on its definition and underlying causes (Elliott & Grigorenko, 2014). In section 2.2, a definition of dyslexia was addressed in terms of the four key components suggested by Tunmer and Greaney (2010). The present dissertation adopts the definition of dyslexia coined by Lyon and colleagues (2003) that is widely referenced in the literature on dyslexia. In sequence, I addressed the underlying causes of this developmental disorder in the context of a causal model proposed by Morton and Frith (1995). Additionally, four contemporary theories of dyslexia were presented: two theories explaining dyslexia in terms of cognitive deficits (the phonological deficit theory and the double-deficit theory) and two theories explaining dyslexia in terms of brain abnormality (the magnocellular deficit theory and the cerebellar deficit theory). The present dissertation supports the phonological deficit theory as it is one of the most widely accepted understanding of dyslexia. Taking into consideration that higher-level language processes are subserved by lower-level language processes, it is believed that lower-level deficits in phonological processing may also affect high-level syntactic processing (Bishop & Bishop, 2001). The present dissertation aims at contributing to this assumption by investigating syntactic processing in dyslexia. Finally, this chapter also reviewed one of the most influential developmental models of reading, a model of typical reading development proposed by

Frith (1986), which indicates that a breakdown in reading development associated with dyslexics occurs at the alphabetic phase.

In the next chapter of the present dissertation, I address the reading process. In particular, I review the model of skilled reading and explain how reading is implemented in the brain. Importantly, in the next chapter I focus on syntactic processing in dyslexia, which is a central issue in this dissertation.

CHAPTER III
UNDERSTANDING THE READING PROCESS

According to Jackson and Coltheart (2001), reading is a complex cognitive ability supported by a mental information-processing system. A printed text serves as the input to this cognitive system, from which the system retrieves information like word pronunciation, meanings, and syntactic relations of words in a sentence. In other words, this cognitive system receives phonological, semantic, and syntactic information from the printed input. Crucially, reader's cognitive system evolves as s/he becomes more proficient and reading skills get more refined (Jackson & Coltheart, 2001).

The primary purpose of reading is to gain meaning from what has been read (Adelman, 2012). Word recognition is essential for text comprehension; however, text comprehension depends not only on the ability to operate at the individual-word level where processes like word recognition, meaning access, and pronunciation retrieval take place. Syntactic processing abilities, i.e., abilities to operate with words at the sentence level, are also thought to be another primary determinant of successful text comprehension (Pollatsek & Treiman, 2015).

The review of literature in this chapter aims at taking a contemporary look at language, and more specifically reading comprehension. Considering this, the present chapter is organized in four main sections. Section 3.1 presents the dual-route model of reading proposed by Coltheart and colleagues (2001) in order to understand how a skilled reader processes written input. In section 3.2, primary brain areas involved in reading are addressed through the modern neurological model of reading proposed by Dehaene (2009). Additionally, the account of the dual-route model of reading is also given at the brain level. Section 3.3 is devoted to the influential and well-referenced model of language processing proposed by Hagoort (2005; 2007) that consists of three core functional components of language: memory, unification and control. Finally, section 3.4 reviews studies that addressed syntactic processing in dyslexia and reported dyslexics' difficulties in this language domain.

3.1 THE DUAL-ROUTE MODEL OF READING

Reading comprehension depends on how accurately words are recognized and how fast the meanings of these words are retrieved and comprehended. Therefore, it is reasonable to distinguish between two distinct but fundamental processes involved in reading: word recognition and word comprehension (Jackson & Coltheart, 2001). An example to illustrate the first process, i.e., word recognition, is a performance on the visual lexical decision task. In this task, the participant needs to determine whether a visually presented string of letters like *knufv* corresponds to a word or a non-word by pressing one response button if the stimulus is a word and another response button if it is not. Speed and accuracy of response reflect the difficulty of lexical processing (Taft, 2013). Importantly, the semantic characteristic of a word, i.e., its meaning, is not necessary to perform this task. On the contrary, the second process, word comprehension, is dependent on the knowledge of the word meaning. For instance, tasks like word-picture matching or synonym judgements measure the participants' comprehension ability.

The distinct processes that include recognizing a printed word and those involved in understanding the meaning of a word can be illustrated by a case of semantic dementia reported by Blazely and colleagues (Blazely, Coltheart, & Casey, 2005).[12] The patient with semantic dementia was submitted to a battery of tasks including a visual word recognition (lexical decision) task and various comprehension tasks. The patient`s performance on a visual word recognition task was highly scored, whereas the performance on written word-picture matching tasks was relatively low. In this case, visual word recognition abilities were relatively intact, whereas word comprehension abilities were severely impaired. Evidence for preserved and impaired reading abilities suggests two distinct reading routes, which are accounted by the dual-route model of reading comprehension proposed by(Coltheart, 1985; Coltheart, Rastle, Perry, & Ziegler, 2001).

The dual-route model is based on the idea that there are two qualitatively distinct mechanisms of information processing, which are employed in making judgments and decisions (Roeckelein, 2006). The first mechanism is associated with a rapid and easy information processing, i.e., the principle of least energy and effort. Therefore, this mechanism posits unconscious and automatic information processing. By

[12] Semantic dementia is a progressive disorder characterized by a deficit of semantic memory, whereas other aspects of cognitive functioning are relatively preserved (Blazely, Coltheart, & Casey, 2005). Patients with semantic dementia demonstrate poor performance on tasks, which require semantic knowledge, such as picture naming, word-picture matching, category fluency (e.g., sort pictures according to living and non-living criterion). On the contrary, performance on tasks measuring other cognitive abilities like working memory, phonological and syntactic processing abilities are relatively intact.

contrast, the second mechanism involves a slow and difficult rule-based information processing, thus requiring conscious and controlled processing. One of the most influential (computational) current models of word processing and reading that is based on the assumption of these two distinct mechanisms, is the dual-route model proposed by Coltheart (Cain, 2010; Eysenck, 2004; Lukatela & Turvey, 1998). In addition, this model has received much support since the 1970s and has been widely adopted in the research on skilled word recognition as well as difficulties with word reading (Caramazza, Miceli, Silveri, & Laudanna, 1985; Coltheart, 1985; Coltheart, Rastle, Perry, & Ziegler, 2001; Forster & Chambers, 1973; Paap & Noel, 1991; Ziegler et al., 2008).

According to the dual-route model, reading comprehension can be achieved via two distinct routes: the direct lexical and the indirect non-lexical route (Figure 3.1). A direct lexical route allows the reader to access the whole-word representation in the lexicon directly, i.e., without mapping the printed word form into its phonological representation (Coltheart, 1985; Coltheart et al., 2001). For instance, a lexical representation of exception words (e.g., the word *yacht*) is accessed directly because knowledge of grapheme-phoneme correspondences would not be helpful to retrieve the meaning of this word.[13] In other words, there is a straight mapping from a printed word to its meaning first and then the phonological representation is accessed once the word has been recognized. Additionally, frequent and familiar words processed through the direct lexical route are read fast. On the contrary, in an indirect sub-lexical route, the reader needs to use knowledge of grapheme-phoneme correspondences to access the phonological representation of a word. Based on phonological information, the reader is able to access a word meaning. The indirect route tends to be slower than the direct route as more processes are involved before the word is recognized. Through the indirect route, the reader can read regular, but unfamiliar words as well as pseudoword by applying knowledge of grapheme-phoneme correspondences. Irregular and unfamiliar words would not be pronounced correctly, for instance *izland* for the word *island*. In literature on reading, the indirect route is also called the non-lexical route (Jackson & Coltheart, 2001), the sub-lexical route (Castles & Coltheart, 1993) or the phonological route (Dehaene & Cohen, 2007).

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[13] Exception or irregular words are words that disobey typical pronunciation rules with grapheme-to-phoneme mappings. These words have irregular spelling patters like silent letters (e.g., *doubt*) or uncommon orthographic structures (e.g., *tough*) (Rathvon, 2004).

Importantly, despite being two distinct routes they coexist and supplement each other during the reading process (Jackson & Coltheart, 2001).[14]

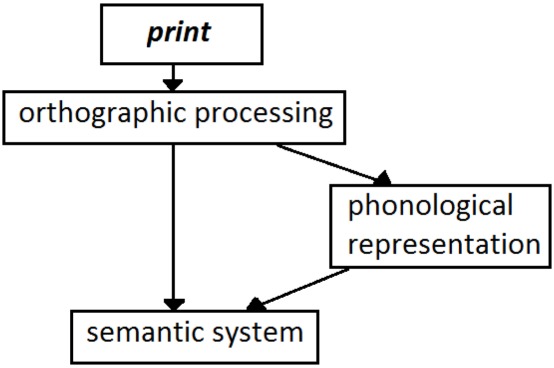

Figure 3.1. The dual-route model of reading comprehension (Jackson & Coltheart, 2001, p.67).

The support to the dual-route model also comes from studies which investigated subtypes of acquired dyslexia in adults, and later the categorization of dyslexic individuals was used to describe individuals with developmental dyslexia (Castles & Coltheart, 1993; Ziegler et al., 2008). Researchers mapped the manifestations of developmental dyslexia to either lexical or non-lexical routes, or a combination of deficits in these two routes (Peterson, Pennington, & Olson, 2013; Sprenger-Charolles, Colé, Lacert, & Serniclaes, 2000; Sprenger-Charolles, Siegel, Jiménez, & Ziegler, 2011; Stanovich, Siegel, & Gottardo, 1997; Thomson, 1999).

Peterson and colleagues (2013) investigated the subtypes of developmental dyslexia in light of predictions made by the dual-route model. The researchers tested a large-scale group of children from 8 to 13 years on a number of reading tests: a pseudoword reading test (e.g., *strale,lobsel*), a phonological choice test, in which participants needed to select one pseudoword that sounds like a real word (e.g., *beal/bair/rabe),* an orthographic choice test, in which participants needed to choose a real

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[14] In literature on reading, there is an alternative to the dual-route model, the single-route analogy model (e.g., Glushko, 1979; Seidenberg & McClelland, 1989). According to the single-route model, a unique mechanism is responsible for reading both exception words and non-words. However, this model has not received much support (Castles & Coltheart, 1993).

word (e.g., *easy – eazy*), a homophone choice test, in which participants were presented with two homophones and needed to select one to answer a question (e.g., *Which is a flower?* - *rose/ rows*). In addition, participants completed an irregular word reading test that included irregular spelled words of varying difficulty (e.g., *island, choir*).

The key findings of this investigation support the distinction between the subgroups of dyslexics accounted by the dual-route model (Peterson et al., 2013). Individuals, who are poor in decoding irregular spelled (exception) words, are called surface dyslexics. Surface dyslexia reflects a deficiency in using lexical (orthographic) skills that in turn lead to limited access to lexical information (sight vocabulary).[15] However, phonological skills of surface dyslexics are intact, which explains why they are relatively good at reading regular words and pseudowords. Individuals with poor phonological skills, but intact orthographic skills are denominated phonological dyslexics. Phonological dyslexics have significant difficulties in reading pseudowords, but their reading of irregular words does not differ from that of regular word. Therefore, differences between surface and phonological dyslexia are a result of an impairment in a specific route of the model (Castles & Coltheart, 1993). In particular, there is a selective damage to the direct lexical route in surface dyslexia, whereas phonological dyslexia reflects a damage to the indirect non-lexical route. In addition to surface and phonology dyslexic subtypes, there is a mixed subtype of dyslexia where a damage occurs to both routes. Individuals with a mixed dyslexia show similar difficulties in reading both irregular words and pseudowords (Schwartz, 2017).

Evidence for phonological and surface dyslexia provides support to the explanation of the reading process proposed by the dual-route model, i.e., there are two distinct routes for reading (Coltheart et al., 2001). Importantly, despite being distinct, the direct and indirect routes coexist and supplement each other (Jackson & Coltheart, 2001). The direct route is responsible for reading words as long as their frequency is high. A skilled reader can instantaneously recognize such word without the need for decoding every single letter. In case of rare or novel words that do not have any representation in the mental lexicon, the direct route is not efficient. In such a case, the indirect route becomes helpful for

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[15] Sight vocabulary refers to the words that an individual can recognize automatically and effortlessly during the reading process. In other words, the process from the printed word (vision) to the lexicon is instant. A reader pronounces sight words correctly, but it is not always a case that s/he knows its meaning (Cohen & Cowen, 2007).

reading new words or words of low frequency, as the indirect route enables to transform letters to sounds and, knowing the pronunciation of a word, its meaning can be accessed. Importantly, reading fluency is dependent on a constant collaboration of both direct and indirect routes and the weight of each route depends on the type of words to be read, that is, whether they are regular, irregular words or pseudowords.

Having reviewed the dual-route model that explains reading in terms of two parallel information-processing routes, it seems essential to discuss the neurobiological evidence for this model. Therefore, the next section reviews major brain areas devoted to the reading process as well as explains how the direct and indirect routes are implemented in the brain.

3.2 THE NEUROBIOLOGY OF READING

Reading is a culturally new ability that was invented around 5400 years ago (Dehaene & Cohen, 2007). Hence, it is commonsensical to remember that originally the human brain was not designated for such a demanding task because reading was not essential for life. Today, reading is taken for granted; however, to enable this skill, the neuronal networks responsible for word processing had to be adjusted through evolution, i.e., they were adapted specifically for reading. The idea that neuronal networks had to go through a process of adaptation is similar to the notions of *exaptation*, a concept of evolutionary biology that is central in the hypothesis of the neuronal recycling process proposed by Dehaene and Cohen (2007;2011)[16].

Earliest understanding of the brain regions employed during the reading process arose from the observations registered more than a century ago by the French neurologist Joseph-Jules Dejerine (Dehaene, 2009). Dejerine conducted the psychological and anatomical examinations of two patients, one with "pure verbal blindness", or pure alexia, and the other with pure alexia and agraphia, but both without any problem in spoken language.[17] The autopsy of the alexic patients revealed

[16] The term *exaptation* was proposed by Gould and Vrba (1982) to refer to the adaptation, in the course of evolution, of a feature that originally served a completely different function to its current function (Coolidge & Wynn, 2011).
[17] In the time of Dejerine (the end of XIX century), the term *pure verbal blindness* was applied to patients who were not able to visually recognize neither letters nor words; however, their visual acuity was intact. They could identify objects and

that a stroke they had suffered affected a portion of the left posterior brain region. More specifically, the neurologist detected that the angular gyrus and supramarginal gyrus in the inferior parietal lobule, the posterior part of the superior temporal gyrus, and the ventral occipito-temporal region were damaged (Swaiman, Ashwal, Ferriero, & Schor, 2011). Based on the anatomical evidence, Dejerine strongly advocated for a disconnection of the left angular gyrus from the visual center in the occipital visual cortex. Connecting these findings with the observed manifestations of the patients, in 1891, Dejerine proposed the first neurological model of reading.

With the advance of imaging techniques like Electroencephalography (EEG), Magnetoencephalography (MEG), and functional Magnetic Resonance Imaging (fMRI), Dehaene (2009) expanded the model proposed by Dejerine in the nineteenth century adding more regions and more connections between them that are involved in reading. Figure 3.2 shows the classic neurological model of reading of Dejerine and the modern model of reading proposed by Dehaene (2009).

Written words are recognized by the visual center located in the occipital cortex (blue area in Figure 3.2). The product of this recognition is transmitted to the ventral occipito-temporal region (red area in Figure 3.2) responsible for the visual analysis of letter and word shape, specifically the visual word form area (VFWA) (Dehaene, 2009; Dehaene & Cohen, 2007, 2011). The VWFA is activated in the early stages of visual processing of words and plays a crucial role in the fast identification of letters and strings of letters. In other words, fluency in reading depends on how fast written input is recognized. The information from the VWFA is distributed to various areas over the left hemisphere that are responsible for more detailed processing such as pronunciation, meaning retrieval and articulation (Dehaene, 2009). [18]

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faces, but were "blind" to letters and all types of words (regular, irregular, and pseudowords). Although today such cases are still identified, the terminology has changed and one can find terms like *pure alexia* or *alexia without agraphia* to describe patients with disruption of reading (Coltheart, 1998).

[18] The VWFA is also called "the brain`s letterbox" by Dehaene (2009, p.53).

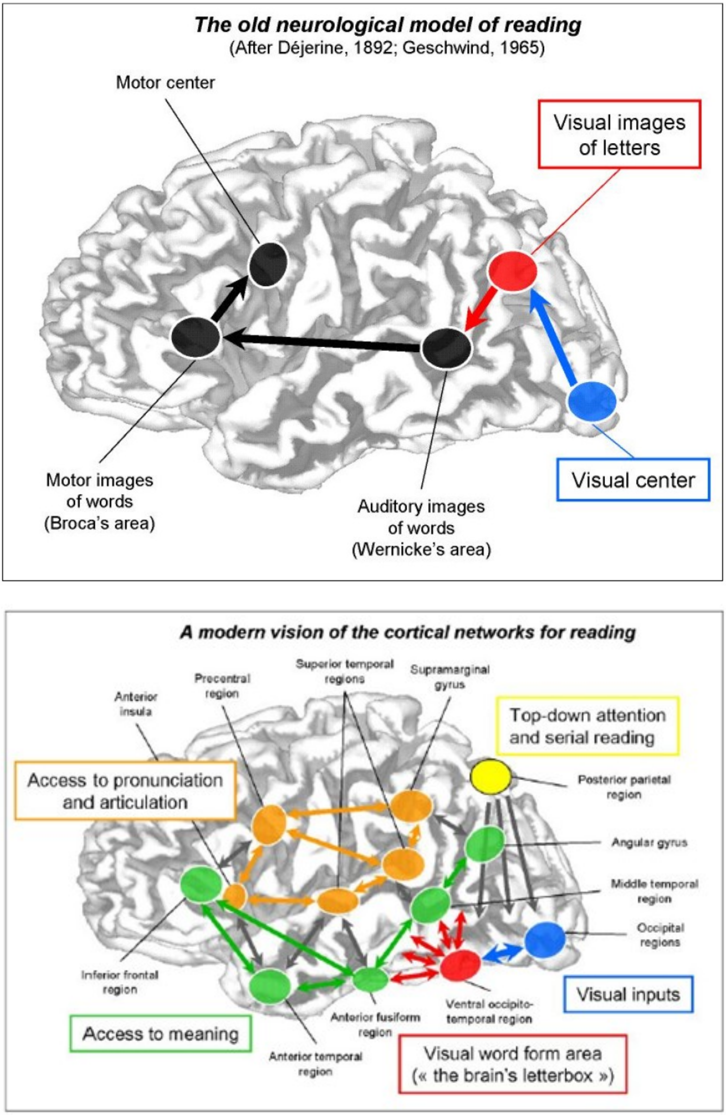

Figure 3.2. The classic neurological model of reading (top) and the modern model of the cortical networks for reading (bottom) (Dehaene, 2009, p.63).

Note. Regions in green and orange are not specific to the reading process; they primarily contribute to the processing of spoken language.

In contrast to the idea of Dejerine about the primary role of the angular gyrus in visual word recognition, Dehaene (2009) defends the role of the VFWA. Dehaene (2009) acknowledges the fact that Dejerine examined the alexic patients, whose VFWA was not directly damaged, but was apparently disconnected and Dejerine's mistake was in correctly detecting the location of the disconnection. Additionally, although the model of Dehaene (2009) has initially originated from the ideas of Dejerine, this model does not support the idea of the classical linear model of brain organization for reading. According to Dehaene (2009), all connections are bidirectional as well as different brain areas can be simultaneously involved in the reading process.

In order to give an objective evaluation of the dual-route model of reading proposed by Coltheart and colleagues (2001), Jobard and colleagues (2003) carried out a meta-analysis of 35 neuroimaging studies that were based on a different methodological and theoretical approach. Using the data of these brain-imaging studies, Jobard and colleagues (2003) described how the two distinct routes are implemented in the brain during reading. In line with the overall results, there are two distinct sets of brain areas dedicated to meaning and sounds (Figure 3.3).

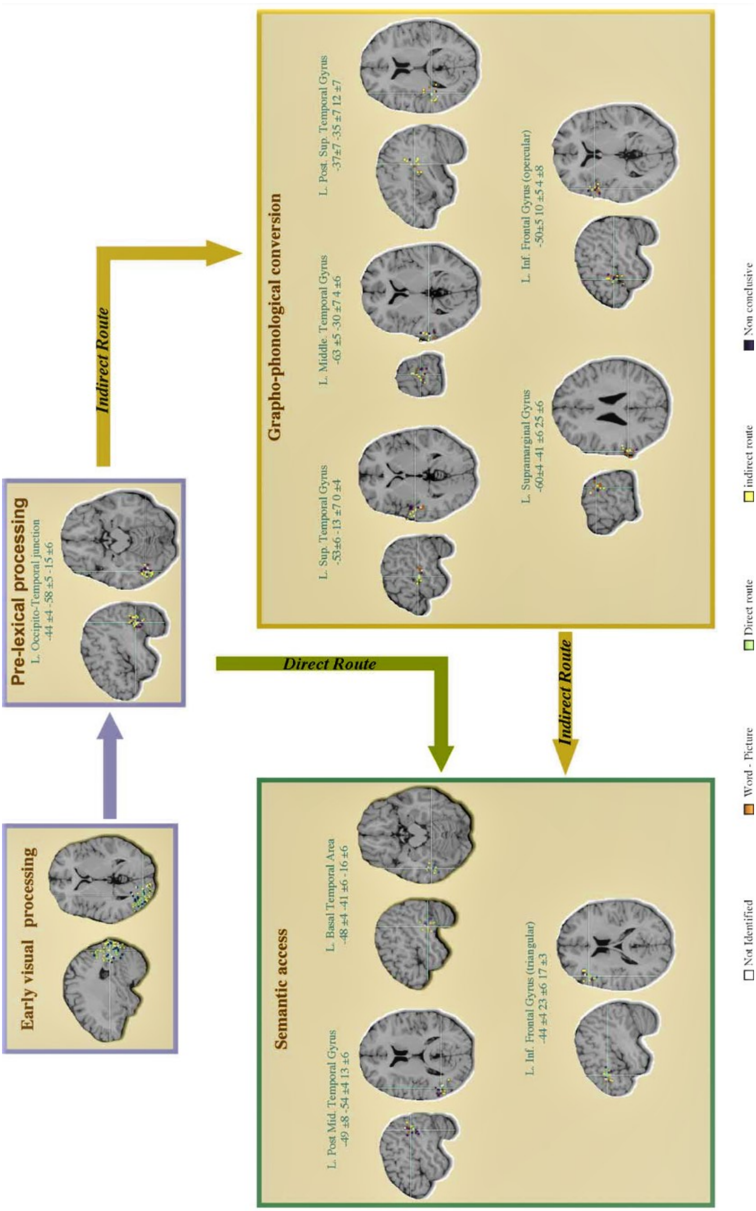

Figure 3.3. The brain implementation of the dual-route model of reading (Jobard, Crivello, & Tzourio-Mazoyer, 2003, p.703).

As can be seen in Figure 3.3, early visual and pre-lexical processing occurs within a left occipito-temporal region, i.e., the visual word form area (VWFA). The grapho-phonological conversion (indirect route) seems to take place in the left lateralized brain structures such as superior temporal areas, supramarginal gyrus, middle temporal gyrus, and the opercular part of the inferior frontal gyrus. Supramarginal gyrus and the opercular part of the inferior frontal gyrus are well known to be involve in meaningful operations on working memory representations (Jobard, Crivello, & Tzourio-Mazoyer, 2003). The lexico-semantic route (direct route) is expected to arise from the co-activation of the VWFA and semantic areas. The semantic areas encompass the posterior part of the middle temporal gyrus, a basal temporal area, and the triangular part of inferior frontal gyrus.

The conclusions of the meta-analysis are in favor of the assumptions of the dual-route model of reading. Taking into account that the neuroimaging studies reported in the meta-analysis investigated brain activations in non-pathological participants, it seems reasonable to think that brain activations of dyslexics would alter during reading-related tasks. Additionally, the dissociation between surface and phonological dyslexia suggests that different brain regions are involved in the direct and indirect word reading processes. Therefore, the subtype of dyslexia could also possibly contribute to detecting locations of altered brain activations in the overall reading network.

The neurological model proposed by Dejerine and later the update version of this model proposed by Dehaene (2009) was based on single word processing. However, reading goes beyond the concatenation of single words. Since the advent of neuroimaging techniques, new neurobiological models of language processing have been proposed: a declarative-procedural model (Ullman, 2001); a dorsal-ventral model (Hickok & Poeppel, 2004); a serial, syntax-first model (Friederici, 2002), and an interactive, memory, unification, and control (MUC) model (Hagoort, 2005, 2007). Some of these models are limited to explain only one aspect of language like single word processing (Hickok & Poeppel, 2004), or lexicon and grammar (Ullman, 2001). The model proposed by Friederici (2002) views the frontal cortex as responsible for strategic processes in language. By contrast, Hagoort`s model (2005; 2007) assumes the integration, or unification, between different types of language information. In particular, the MUC model assumes that the unification operations occur at the main syntactic processing level and attributes a central role of the left inferior frontal gyrus (LIFG) in syntactic unification. The model has received extensive empirical evidence supporting the proposed distribution of labor between the core language regions in the left hemisphere (Hagoort, 2016). Therefore, the review of this model will be crucial to elucidate the findings of the present dissertation that investigates language comprehension at the sentence level. Hence, the MUC model is discussed in the next section.

3.3 MEMORY, UNIFICATION AND CONTROL (MUC) MODEL

To begin with, it is important to state that, in general, models of language processing focus on two processes: information retrieval from long-term memory (LTM) and combinatory operations that form meaningful structures from this information (Hagoort, 2007). However, Hagoort (2005; 2007) argues that language processing goes beyond these two processes and that there is an additional process at stake, cognitive control. Based on these assumptions, Hagoort (2005; 2007) proposed the Memory, Unification and Control (MUC) model that provides a plausible account of both language production and language comprehension.

The MUC model accounts for memory retrieval (the Memory component) and combinatorial operations (the Unification component), and adds a third function component of language processing, the Control component. Additionally to the description of the functional components of language processing, the MUC model provides a neurobiological account of the underlying brain areas for language (Hagoort, 2005; 2007). In other words, the MUC model indicates specific brain areas that are involved in each functional component of language processing. Figure 3.4 illustrates the three components of Hagoort's (2005; 2007) model at the neuronal level.

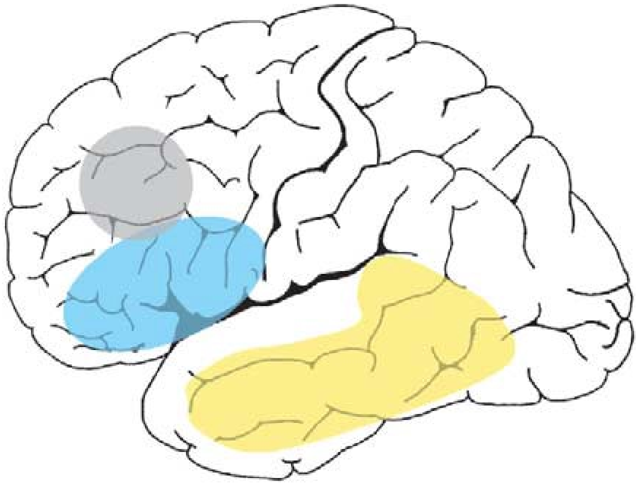

Figure 3.4. The Memory, Unification and Control (MUC)(Hagoort, 2005, p.421). Note. The three components of the MUC model assigned to the areas of the left hemisphere: Memory (yellow) in the left temporal cortex, Unification (blue) in Broca's area (BA44 and BA45) and adjacent cortex (BA47 and BA6), and Control (grey) in dorsolateral pre-frontal cortex.

The first component of the model, Memory, is responsible for storing and retrieving all language information (phonological, semantic and syntactic) from the mental lexicon. Based on brain imaging studies, Hagoort (2005; 2007) argues that memory retrieval has its own brain areas for sustaining memory processes. Phonological information processing is assumed to activate the area of the central and posterior parts of superior temporal gyrus (STG) up to the superior temporal sulcus (STS). It is argued that semantic information processing activates more inferior areas over the left hemisphere, in particular the left middle and inferior temporal gyri. Syntactic information processing engages the left posterior superior temporal cortex (Wernicke's area, BA22).[19] Hence, the Memory component mainly employs the left temporal cortex.

The second component, Unification, is essential to the MUC model (Hagoort, 2005). The model proposes that unification or integration of

[19] BA stands for Brodmann area. The cerebral cortex was divided into different areas based on cytoarchitecture of cells and numbered by a German neuroscientist, Korbinian Brodmann (Greenstein & Greenstein, 2000).

language information takes place at the phonological, semantic and syntactic levels. Importantly, unification operations occur at these three levels simultaneously and in parallel. According to Hagoort (2005), unification of phonological and semantic information is a separate process from syntactic unification. Nevertheless, phonological and semantic unification is equally as important as syntactic unification. Unification at each level is described next.

At the level of phonology, lexical items are combined into acoustic, more specifically into intonational phrases. Prosodic voice cues like pauses and changes in intonation can signal the importance of a specific part of a sentence. For instance, in the beginning of a conversation between two speakers, the phrase *How are you?* is characterized by different intonational profiles. The profile depends on the conversation order between speakers where the first speaker highlights the word *are* and the second speaker after responding to this question highlights the word *you*. The role of phonological unification is to select either of these intonational profiles. Phonological processing is proposed to employ the superior areas of the left hemisphere, in particular a part of Broca's area (BA44) and parts of BA6 (Hagoort, 2005).

At the level of semantics, lexical items are combined into larger structures based on the established context (Hagoort, 2005). In English, many words have multiple meanings. For instance, the word *bank* can mean the land along the edge of a river or a financial institution. The role of semantic unification is to select the most fitting meaning of a lexical item according to the context. The MUC model suggests that semantic unification is closely related to syntactic unification because a sentence is processed semantically right after it has been processed syntactically. Based on empirical evidence, the network of brain areas BA47 and BA45 is involved in semantic processing (Hagoort, 2005).

At the syntactic level, lexical items (content words) are combined to form multi-word sentences according to the rules of grammar (Hagoort, 2005). Syntactic information of these items is stored in the mental lexicon (memory). As proposed by the MUC model, lexical items with their associated syntactic rules are retrieved from the mental lexicon sequentially. Hence, syntactic unification occurs incrementally, in the order that lexical items are presented. Since every lexical item possesses a limited set of syntactic nodes (e.g., clause, noun phrase, verb phrase), there is also a limited amount of plausible combinations. For instance, the content words *dog, eat* and *meat* can be combined into sentences like *The dog ate the meat* or *The meat was eaten by the dog* with the help of such function words as *the* (determiner), *was* (auxiliary verb), *by* (preposition).[20] The role of syntactic combination is to select the most appropriate combination in the context of communicative intentions. Broca's area, which comprises BA44 and BA45, is assumed to be involved in syntactic processing (Hagoort, 2005).

Finally, the third component, Control, plays a crucial role for effective communication (Hagoort, 2005). The Control component is responsible for planning and execution of verbal actions. For instance, attention control enables individuals to use language appropriately in a specific communicative situation despite possible intervening factors such as sound effects or visual inserts. These higher-order control operations for language engage areas in the prefrontal cortex, more specifically the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPC, BA 46/9) (Hagoort, 2005;2007).

Looking at the neural correlates of the MUC model, the central claim of the model is that the left temporal cortex significantly contributes to memory, i.e., information storage and retrieval, and Broca`s area (BA44 and BA45) and the adjacent language-relevant cortex (BA47 and BA6) play a fundamental role in unification (Hagoort, 2005). There is a substantial body of evidence that semantic unification is subserved by the left inferior frontal cortex (LIFC), in particular BA45 and BA47. As for phonological unification, BA44 and BA6 are suggested to be recruited. With regard to the syntactic unification, two areas are considered to be important: the left posterior superior and middle temporal gyrus and the left prefrontal cortex, in particular BA44 and BA45.

It is essential to report the recent functional magnetic resonance imaging (fMRI) study conducted by Snijders and colleagues (2009) that provided direct empirical support for the distinct distribution of labor between the left temporal cortex and the left inferior frontal gyrus (LIFG), or Broca`s area during sentence comprehension (Hagoort, 2016). The study of Snijders and colleagues (2009) investigated the role of these two brain areas to the retrieval of lexical-syntactic information and the integration of this information into multi-word sentences. Twenty-eight right-handed participants (14 females, age ranges from 18 to 35) took part in the experimental study (Snijders et al., 2009). All of them were native speakers of Dutch and did not have any history of neurological disorder or brain injury. Participants read 68 Dutch sentences and 68 word

[20] Content words are defined as lexical items that are responsible for the principal meaning of the sentence, whereas function words carry a grammatical function (tense, number, definiteness, etc.) without any conceptual meaning, but they are essential to form meaningful sentences (Corver & Riemsdijk, 2001).

sequences with ambiguous words (noun vs. verb). Snijders and colleagues (2009) predicted that syntactic unification would occur for sentences rather than for word sequences and the same would be true for ambiguous rather than unambiguous conditions within sentences. The findings confirmed the hypothesis proposed by Hagoort (2005) and the predictions made by Snijders and colleagues (2009) about the involvement of the LIFG in syntactic unification. Additionally, the activation of the left posterior middle temporal gyrus was more enhanced for ambiguous than unambiguous conditions, thus confirming the prediction of this area subserving the retrieval of lexical-syntactic information from the mental lexicon.

The review of the MUC model is essential for the present dissertation, especially for the main prediction of Study II that investigated syntactic priming in dyslexia at neuronal level. Study II predicted the involvement of the LIFG in combinatorial, or unification operations at the sentence level. In addition to this model, it seems also crucial to review several behavioral and neuroimaging studies that explored sentence reading processing in dyslexia. Hence, this issue is addressed in the next section.

3.4 SYNTACTIC PROCESSING IN DYSLEXIA

Successful reading does not depend only on efficient processing and understanding of single words, but also on efficient processing and understanding of multiword sentences. Therefore, in addition to phonological and semantic information of words, syntactic information is essential for reading as this information determines the way words are related to each other in a sentence (Friederici, 1998). For examples, the words *boy, kiss* and *girl* can form sentences like *The boy kissed the girl* (active voice) or *The boy was kissed by the girl* (passive voice). The interpretation of each sentence is different despite the same superficial sequence of the content words (*boy….kiss….girl*). The correct interpretation of the passive sentence is only possible when the auxiliary verb *was* and the preposition *by* are perceived as the grammatical markers of the passive voice structure. This example provides clear evidence of how knowledge of syntactic rules and competence to use them is essential for reading comprehension.

Syntactic processing is a complex cognitive ability whereby a language user can produce and comprehend multiword sentence structures (Wilson et al., 2010). In particular, a language user can manipulate a set of rules that determine how isolated words can be combined in different sequences of words in order to create meaningful sentences, i.e., the ability to establish who is doing what to whom in a complex sentence structure like the passive voice. Additionally, efficient reading relies on rapid and simultaneous access to syntactic rules (Batterink & Neville, 2013).

One of the main questions of this dissertation is whether the linguistic impairment associated with dyslexia is limited to phonology or whether it goes beyond this language domain and extends to syntax. As stated above, understanding a sentence does not require only a phonological analysis of single words, but it also requires a syntactic analysis of how these words are related to each other in a sentence. In the literature on dyslexia, there are important indications that dyslexics` ability to process and interpret sentences is impaired (Altmann et al., 2008; Arosio et al., 2016; Breznitz & Leikin, 2000; Cantiani et al., 2013; Leikin & Assayag-Bouskila, 2004; Robertson & Joanisse, 2010; Rüsseler et al., 2007; Waltzman & Cairns, 2000; Wiseheart et al., 2009). However, despite many years of research, there is still a debate as to the source of impaired syntactic abilities in dyslexia: whether dyslexics have a delay in developing syntactic knowledge (Lyytinen et al., 2001; Wilsenach & Wijnen, 2004) or whether they suffer from a general processing deficit that impedes dyslexics to perceive syntactic functions of words (Breznitz & Leikin, 2000; Cantiani et al., 2013; Rüsseler et al., 2007).

The idea of a delayed development of syntactic knowledge is supported by the structural lag hypothesis proposed by Shankweiler and Crain (1986). In its general form, the structural lag hypothesis states that linguistic knowledge is essential for reading and that many beginning readers do not have a good command of this knowledge. According to the researchers, linguistic knowledge contains two levels: phonological and syntactic. A lag or a deficiency at the phonological level is related to difficulties with phonological analysis and orthographic decoding, i.e., lower levels of language processing. A lag at the syntactic level reflects difficulties with sentence parsing, i.e., the higher level of language processing. Importantly, they agree that the syntactic lag hypothesis cannot alone explain all difficulties, especially difficulties at lower levels of language processing (Shankweiler & Crain, 1986). Hence, the researchers suggest two possible explanations: either there might be a unitary deficit that affects all language domains (phonology and syntax), or there might be specific deficits at more than one level of language and if difficulties have a common source, then a syntactic deficiency could be derivative from the deficiency in phonological abilities. There are several longitudinal studies that report a delayed morpho-syntactic development in pre-school children at genetic risk of dyslexia (Lyytinen et al., 2001; Scarborough, 1991; Wilsenach & Wijnen, 2004).

In contrast to the structural lag hypothesis, there are strong grounds for supposing that reading difficulty could be explained by general processing limitations (Shankweiler & Crain, 1986). A basic premise of the processing limitation hypothesis is that the source of reading difficulty goes beyond the phonological and syntactic knowledge of a language user because there is a failure in working memory, a processor that is essential for phonological and syntactic knowledge integration. In other words, there are no gaps in knowledge of phonology and syntax, but there is a deficiency in integrating this knowledge. Support for the processing limitation hypothesis comes from studies where researchers demonstrate that dyslexics are familiar with complex syntactic structures, but they just fail to use them correctly in experimental contexts (Bar-Shalom, Crain, & Shankweiler, 1993; Jiménez et al., 2004; Robertson & Joanisse, 2010; Rispens & Been, 2007; Wilsenach, 2006; Wiseheart et al., 2009).

Controversial evidence of impaired syntactic abilities in dyslexia comes from studies across different languages: Dutch (Rispens et al., 2004; Wilsenach, 2006), German (Rüsseler et al., 2007; Sabisch et al., 2006), Hebrew (Breznitz & Leikin, 2000; Leikin, 2002), and Brazilian Portuguese (Oliveira et al., 2012; Mendes et al., 2010). Additionally, different experimental designs also evidenced dyslexics' deficiency in syntactic processing: sentence-picture matching (Robertson & Joanisse, 2010; Waltzman & Cairns, 2000); syntactic judgment on verb agreement (Cantiani et al., 2013; Rispens & Been, 2007; Rispens, Roeleven, & Koster, 2004); comprehension of complex syntactic structures such as relative clauses (Arosio et al., 2016; Bar-Shalom et al., 1993; Cardinaletti & Volpato, 2014; Leikin & Assayag-Bouskila, 2004; Mann et al., 1984; Rüsseler et al., 2007; Wiseheart et al., 2009) and passive sentences (Cardinaletti & Volpato, 2014; Leikin & Assayag-Bouskila, 2004) Reggiani,2009). Of interest for the present dissertation is to review studies that investigated the processing of passive sentences in dyslexia. Additionally, to the best of my knowledge, two studies explored syntactic processing in Brazilian Portuguese dyslexic children, and these studies are worth reviewing in the context of Study I and Study II of the present dissertation that investigated dyslexic children in Brazil. Moreover, one study, which attempted to provide evidence for the neural processes associated with reading sentences in children with dyslexia, also deserves special attention since Study II of the present dissertation addressed this issue. Thus, these studies are reviewed next.

Cardinaletti and Volpato (2014) investigated the comprehension and production of relative clauses and passive sentences in a group of 10 university students with dyslexia ranging in age from 20 to 25 years. Their performance on the comprehension and production of relative clauses was compared to two groups of non-dyslexic participants (16 adolescents ranging in age from 14;1 to 17;5 years, and 16 adults ranging in age from 20 to 34 years). Their performance on the comprehension and production of passive sentences was compared to a group of 17 university students ranging in age from 20 to 23 years. Comprehension was assessed by using picture and agent selection tasks, and production was assessed by using oral elicitation tasks. The results showed that dyslexics had greater difficulty in the comprehension and production of relative clause sentences rather than passive sentences. The difference in processing two distinct structures was attributed to the length of the syntactic dependency in relative clause sentences that places an additional load on the computational system, whereas passive sentences contain shorter dependencies, thus being easier to memorize and process (Cardinaletti & Volpato, 2014).

Leikin and Assayag-Bouskila (2004) were interested in the influence of syntactic complexity on sentence comprehension in Hebrew dyslexic children aged 10-11 years. Participants' syntactic abilities were measured by using three experimental tasks: a syntactic judgment task, a sentence-picture matching task, and a sentence correction task. In each task, there were five syntactic constructions that varied in the level of syntactic complexity: active, passive, conjoined, object-subject relative, and subject-object relative. The researchers controlled the length of sentences and the number of propositions in the sentences. Additionally, they measured participants' reading and general abilities, including reading comprehension, phonological awareness, and working memory. The results demonstrated that dyslexics were less accurate and slower than non-dyslexics in all reading tasks and in the auditory sentence comprehension tasks. Importantly, the differences between the groups were robust across three experimental tasks as well as across syntactic constructions (Leikin & Assayag-Bouskila, 2004). Taking into considerations these findings, the researchers concluded that the factor of syntactic complexity is a relatively independent aspect of sentence comprehension. Moreover, Leikin and Assayag-Bouskila (2004) argue that the syntactic competence of dyslexics is not affected and the source of sentence comprehension difficulties may be attributed to a sentence processing weakness that is associated with phonological and memory impairments in dyslexia.

Oliveira and colleagues (2012) investigated reading processes in three groups of participants, native speakers of Brazilian Portuguese: students with dyslexia (Group 1), learning disabilities (Group 2), and students with good academic performance in reading (Group 3). In total, 60 students of public elementary schools participated in this study, 20 students in each group, with age ranging from 8;2 to 10;11 years. All participants were submitted to the Brazilian adaptation of the Assessment of Reading Processes (PROLEC-R) with four blocks of tasks: identification of letters, lexical, syntactic and semantic processes.[21] It is worth pointing out that the third block (syntactic processes) consisted of performing two tasks: grammar structure and punctuation task. The grammar structure task measures the participant's capacity to process sentences with different grammatical structures: active voice, passive voice, and focused complement.[22] In the punctuation task, students received a short text and need to use punctuation marks accordingly. The results showed that Group III (good readers) performed much better in all tasks in comparison to Group I (dyslexics) and Group II (participants with learning disabilities). However, Group I outperformed Group II in the punctuation task (syntactic), clauses comprehension, and text comprehension. Therefore, the researchers concluded that dyslexics` syntactic and semantic abilities were greatly affected by deficient phonological awareness (Oliveira, Cardoso, & Capellini, 2012).

Mendes and colleagues (2010) also explored syntactic processing in Brazilian dyslexic children and children without any history of speech-language or reading impairments, all students of private elementary schools. There were 16 participants in each group with age ranging from 9 to 11 years. In particular, Mendes and colleagues (2010) were interested in dyslexics' sensitivity to subject-verb agreement in relative clause sentences. The experimental task had a self-paced reading paradigm with

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[21] RROLEC-R is a battery of reading assessment to children from 6 to12 years, which was validated in Spain with a sample of 920 students (Cuetos et al., 2009). This battery includes four fundamental processes involved in reading: identification of letters (tests: 1. Name sounds of letters, 2. equal-different), lexical processes (tests: 3. read words; 4. read non-words), syntactic processes (tests: 5 grammatical structures. 6. punctuation), and semantic processes (tests: 7. comprehension of sentences; 8. understanding of texts and 9. oral comprehension). This battery was also adopted for European Portuguese by Figueira and colleagues (2011).

[22] In the focused complement structure in European Portuguese, for example, *O gato, ataca-**o** o rato* (the English translation *The cat, it attacks the mouse), o* next to the verb refers to the agent (i.e., *cat*) that performs the action (Simões, 2012).

16 target sentences and 20 filler sentences. Each sentence was accompanied by a comprehension question with two answer alternatives. Reading times and response accuracy were recorded. The results showed that there was significant difference in the on-line processing between dyslexic and non-dyslexic groups, in which dyslexics were much slower than non-dyslexics, but no difference in the off-line processing, i.e., response accuracy, were found between the groups. The researchers concluded that although dyslexics took much more time to process sentences, they did not have difficulty in comprehending them (Mendes, Maia, & Gomes, 2010).

Rimrodt and colleagues (2009) were interested in examining the neurological correlates of sentence comprehension in children with dyslexia. The researchers recruited 29 participants, with age ranging from 9 to 14 years (15 non-dyslexics and 14 dyslexics). Participants performed a sentence comprehension task that was alternated with a word-reading task. The sentence comprehension task was presented with a sequence of six words in each sentence and participants had to decide whether a sentence was meaningful or not. In the word reading task, participants had to read a string of 6 words (nouns) within each block and decide whether a word had been previously repeated in the block. In both tasks, response time and task accuracy were measured. The results showed that dyslexics had more brain activation than non-dyslexics in several areas associated with linguistic processing (left middle and superior temporal gyri) and attention and response selection (bilateral insula, right cingulate gyrus, right superior frontal gyrus, and right parietal lobe) that are consistent with previous findings of more extensive brain activation during reading in impaired readers in comparison to non-impaired readers (Rimrodt et al., 2009). These findings are especially important for the explanation of the results in Study II that aimed at understanding the cognitive and neural resources employed by dyslexics during reading performance.

Taken together the findings of syntactic processing in dyslexia, it can be concluded that dyslexics demonstrate difficulties when processing sentences. These difficulties can be evidenced at the behavioral level (longer response time and less accuracy) and at the neuronal level (extensive brain activation in language areas). Additionally, there are strong grounds to suggest that these difficulties are associated with a failure to integrate syntactic knowledge during on-line processing rather than impaired syntactic knowledge. Hence, these findings are in line with the processing limitation hypothesis proposed by Shankweiler and Crain (1986) where it states that syntactic knowledge in dyslexics is not affected, but there is a deficiency in integrating each incoming word with preceding and subsequent words. This integration is essential for efficient sentence comprehension.

In summary, Chapter III sought to present the state-of-the-art review on the reading process in terms of theories and empirical evidence. First, the influential dual-route model of reading proposed by Coltheart and colleagues (2001) is addressed. This model explains how a skilled reader processes written input, in particular either via the direct lexical route or the indirect non-lexical route. In sequence, I reviewed the neurological model of reading of Dehaene (2009) and discussed representation of the two reading routes proposed by Coltheart and colleagues (2001) at the neuronal level in the brain. In addition to the models of single word processing, the well-referenced model of language processing of Hagoort (2005; 2007) is reviewed. I discussed the three core components of the model, memory, unification, and control, in terms of their functions as well as a network of brain areas that support these particular language functions. Finally, this chapter ended with the discussion of controversies regarding the source of impaired syntactic abilities in dyslexia. In addition, empirical evidence for a syntactic weakness in dyslexia was reported. It is noteworthy to mention that previous studies that revealed syntactic processing difficulties in dyslexics, employed different experimental designs, like sentence-picture matching, syntactic judgments, sentence comprehension. To the best of my knowledge, the syntactic priming paradigm has never been used as a tool to tap into sentence processing during comprehension in dyslexia. Therefore, the following chapter (Chapter IV) describes the syntactic priming paradigm as the method used to investigate sentence processing as well as the theoretical account of syntactic priming effects. Moreover, the principles of the experimental design adopted in the present dissertation as well as the preliminary results of the pilot study are also reported.

CHAPTER IV
SYNTACTIC PRIMING PARADIGM

The present chapter aims at providing insights into the syntactic priming paradigm that was used as a method to investigate sentence processing in language comprehension in dyslexia. In line with the proposal, this chapter is organized into eight sections. First, the characteristics of the phenomenon of syntactic priming are presented (Section 4.1). Section 4.2 and Section 4.3 review empirical evidence of syntactic priming in language production and language comprehension, respectively. Discrepancies in the production and comprehension literature on syntactic priming are reported in Section 4.4. In section 4.5, mechanistic explanations for syntactic priming effects in both language production and language comprehension are addressed by discussing the two current theoretical accounts: a residual activation account (Pickering & Branigan, 1998), and an implicit learning account (Bock & Griffin, 2000). Considering that, a great portion of studies investigated syntactic priming in healthy adult populations, for the purpose of the present dissertation it seems commonsensical to review empirical evidence of syntactic priming in special populations (Section 4.6). Then, the general syntactic priming paradigm adopted for the studies with dyslexics in this dissertation is described in Section 4.7. Finally, the results of the pilot study based on this syntactic priming paradigm are presented and discussed in section 4.8.

4.1 PHENOMENON OF SYNTACTIC PRIMING

The first use of the term *priming* appeared in a 1951 article of the American psychologist Karl Lashley (Chartrand & Jefferis, 2004). Since then, the term *priming* has been used in psychology to address a central phenomenon of behavior, repetition (Pickering & Ferreira, 2008). In experimental psychology, repetition is assumed to be a behavior that is relatively similar to the behavior an individual has previously demonstrated, or that an individual has observed from others before. More specifically, priming accounts for effects where prior exposure to one specific information (*prime*) facilitates the processing of that or related information (*target*) in the consecutive situation. The definition of priming proposed by Chartrand and Jefferis (2004) states that:

An individual's experiences in the environment temporarily activate concepts that are mentally represented. The activation of these concepts, which can include traits, schemata, attitudes, stereotypes, goals, moods, emotions, and behaviors, heightens their accessibility. These concepts are said to be primed; that is, they become more likely to influence one's subsequent thoughts, feelings, judgments, and behaviors (p.854).

In the linguistic domain, priming embodies various aspects of knowledge associated with language processing, including phonetic, phonological, orthographic, morphological, lexical, semantic, and syntactic priming (McDonough & Trofimovich, 2011).[23] Besides the differences in the aspect of language, all types of priming have the same investigative interest: how prior exposure to language forms or meanings influences subsequent language processing. The review of all priming types is beyond the scope of this section because only syntactic priming is under investigation in this dissertation.

Syntactic priming (in language production studies also known as structural priming and structural persistence) is the facilitation of sentence processing which occurs when a target sentence has the same or related syntactic structure as a prime sentence (Bock, 1986). In other words, syntactic priming is associated with the priming of language form (the grammatical structure). Syntactic priming research has investigated the strength of syntactic priming effects in a variety of target structures: datives (Bock, 1986); transitives (Bock & Griffin, 2000); locatives (Hartsuiker, Kolk, & Huiskamp, 1999); subordinate clauses (Hartsuiker & Westenberg, 2000). In addition, syntactic priming effects have been found in both language modalities (production and comprehension) as well as across these modalities (from comprehension to production and

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[23] It seems valid, however, to provide a brief explanation of other types of priming. According to McDonough and Trofimovich (2011), phonetic priming refers to the overlap of phonetic features between a prime and a target (e.g., the word *bat* and the word *peel* share the phonetic feature (bilabial stop) of the initial consonants). Phonological or phonemic priming refers to the overlap of phonological form in terms of individual segments, syllable onsets or rhymes (e.g., the rhyming pair of the word *eight* and the word *mate*). Orthographic priming refers to the overlap of orthographic form (e.g., the word *touch* and the word *couch*). Lexical priming refers to the overlap of lexical units (e.g., the sentence *John kissed Mary* and the sentence *The girl kissed her mother* share the same verb in addition to the active voice structure – syntactic priming). Finally, semantic priming refers to the overlap of semantic classification (e.g., the word *bread* and the word *butter*).

from production to comprehension) (for a critical review see Pickering & Ferreira, 2008; Tooley & Traxler, 2010).

In studies of language production, behavioral evidence for syntactic priming is observed in the form of syntactic structure choices. For example, when the speaker hears a message encoded in the passive voice (*prime*), s/he is likely to choose the same structure rather than its equally acceptable alternative (the active voice structure) for a subsequent utterance (*target*) (Bock & Loebell, 1990). However, behavioral evidence for syntactic priming in production is not restricted to the probabilities of reusing a particular syntactic structure by the speaker. The speaker may also be faster in producing sentences with the same structure as the prior sentence that provides behavioral evidence in the form of reduced speech onset latencies (Corley & Scheepers, 2002; Segaert et al., 2016; Smith & Wheeldon, 2001).

In studies of language comprehension, behavioral evidence for syntactic priming is found in faster reading times during target-sentence processing. For instance, when the individual reads a sentence in the passive voice (*prime*), the subsequent sentence (*target)* with the same structure is processed more quickly (Noppeney & Price, 2004). In other words, faster reading times are associated with the facilitation in processing. In addition, syntactic priming in comprehension is also associated with anticipation of eye movements to pictures (Arai, van Gompel, & Scheepers, 2007) and faster ambiguity resolution in picture-matching task (Branigan, Pickering, & McLean, 2005).

With advances in the use of sophisticated brain imaging, the effects of syntactic priming have been investigated at the neuronal level (Noppeney & Price, 2004; Segaert, Kempen, Petersson, & Hagoort, 2013; Weber & Indefrey, 2009). When syntactic structures are primed during either language production or comprehension, the facilitation of syntactic processing shows itself in syntax-related brain areas (Menenti, Gierhan, Segaert, & Hagoort, 2011; Segaert, Menenti, Weber, Petersson, & Hagoort, 2012). Facilitation effects, which are related to less brain activity (repetition suppression effects), have been identified in the left frontal and temporal brain regions (Noppeney & Price, 2004; Segaert et al., 2013, 2012; Weber & Indefrey, 2009).

Both behavioral and neuroimaging measures of syntactic priming effects can provide valuable insights into the parsing mechanism underlying syntactic priming, in other words, the mechanism that would be able to account for faster processing during comprehension and faster responses in production as well as the repetition suppression effect in the brain. Moreover, running behavioral and neuroimaging syntactic priming experiments can contribute to understanding the relationship between syntactic priming effects at the behavioral level and at the neuronal level.

Syntactic priming has also been observed in different languages, thus providing additional support to this phenomenon: English (Bock & Griffin, 2000), Dutch (Hartsuiker & Kolk, 1998a; Segaert et al., 2013), Spanish (Flett, 2006), Chinese (Chen, Xu, Tan, Zhang, & Zhong, 2013) as well as in bilinguals (Hartsuiker, Pickering, & Veltkamp, 2004; Weber & Indefrey, 2009).

In light of the above, it can be concluded that syntactic priming is a multifaceted phenomenon that manifests itself in different syntactic structures, different linguistic settings, and different languages, thus suggesting that syntactic priming might be a universal feature of the human language system. From this perspective, it seems reasonable to address empirical evidence of syntactic priming next.

4.2 EMPIRICAL EVIDENCE FOR SYNTACTIC PRIMING

Syntactic priming has become an important topic in psycholinguistics and has been extensively used to investigate syntactic processing (Bock, 1986; Branigan et al., 2005; Segaert et al., 2013). In language studies, there is vast and converging empirical evidence for the facilitation effects of syntactic priming. This section is devoted to recent and influential studies that investigated the effects of syntactic priming in language production (4.2.1), language comprehension (4.2.2), across language modalities (4.2.3), and in special populations (4.2.4).

4.2.1 Syntactic priming in language production

The earliest report of syntactic priming comes from Levelt and Kelter (1982) who conducted several experiments with various question-answering situations. In one of the experiments, the researchers telephoned a total of 228 shops in Nijmegen, the Netherlands, and made questions about the closing time on Saturday in two equivalent ways, either *What time does your shop close?* or *At what time does your shop close?*.[24] As can be seen, the presence of the preposition *at* was the only difference between these questions. Surprisingly, the responses had a remarkable consistency with the questions made. When asked a prepositional question, the shop owners replied with the preposition *at* (e.g., *At five o'clock*), whereas when the question did not have the

[24] The English translation is provided for questions and answers. All question-answering situations were in Dutch (Levelt & Kelter, 1982).

preposition *at*, the answer was *Five o'clock*. In light of these findings, (Levelt & Kelter, 1982) concluded that speakers are influenced by the primed information and are more prone to reusing it in their subsequent utterances. Moreover, the researchers suggested that syntactic priming may have an impact on production fluency. Reusing available information (an effect of practice) presupposes more economical planning time to generate speech, thus leading to reduced response latencies.

Very few studies have addressed syntactic priming in language production through response latencies (Corley & Scheepers, 2002; Segaert et al., 2016; Smith & Wheeldon, 2001). In a similar line, Corley and Scheepers (2002) claim that syntactic priming does not only influence the choice of a syntactic structure, but also the fluency of its production. In the on-line sentence completion task with prepositional and double object datives, besides the response tendencies, onset latencies were recorded (Corley & Scheepers, 2002). The findings revealed that participants took less time to complete target sentences when they shared the same syntactic structure with the previous prime completions. Smith and Wheeldon (2001) conducted several on-line experiments based on a picture description task with noun structures. Participants described the directions of moving objects on a computer screen. The results showed that participants produced target sentences by approximately 50ms faster when they followed the production of syntactically similar sentences. In the study of Segaert and colleagues (2016), syntactic choices as well as production latencies on primed transitive structures were measured. Participants described pictures that depicted two people performing transitive actions in one sentence either with an active or passive sentence. Based on priming findings, the researchers found latencies effects for actives, but syntactic preference effects for passives.

In a seminal paper, Kathryn Bock (1986) reported the results of a set of experiments where participants needed first to repeat sentences and then describe pictures depicting unrelated events in one sentence. In all three experiments, the researcher observed the same tendency. When participants repeated a sentence with a particular structure, they were more likely to use that structure again to describe the picture afterwards. In other words, the previously processed sentence (*prime)* influenced the production of a subsequent sentence (*target)*. For instance, in one of the experiments, participants had to listen to and repeat sets of transitive priming sentences whether with the active or passive voice structure. If participants received as an input an active sentence like *A janitor cleans the floors daily*, they were prone to describing the following picture that illustrated a completely different event with the same sentence structure.

On the contrary, if they heard a sentence with the passive voice structure, they would probably describe the subsequent picture with a janitor cleaning the floor using the passive voice structure like *The floors are cleaned by a janitor* and not the active one. The same tendency persisted for a double object (DO) structure versus a prepositional object (PO) structure investigated in the other experiment. Importantly, as the content of sentences and pictures did not overlap, Bock (1986) concluded that these priming effects were specific to language form, i.e., a sentence structure, and did not depend on language meaning. She advanced the claim, then, that these results support the idea of abstract properties of syntactic representations along with the proposal that syntactic priming being a useful paradigm to investigate syntactic processing (Bock, 1986).

Through the work of Bock (1986) and colleagues (Bock & Griffin, 2000; Bock & Loebell, 1990), the experimental research on syntactic priming has gained prominence. A variety of experimental designs have been employed to elicit syntactic priming during language production. Experimental designs may include memory tasks, in which participants need to repeat primes presented in an oral or written form and then orally describe pictures (Bock,1986); picture description, in which participants are induced by instructions to describe a picture using a particular structure, i.e., a prime is self-produced, and then describe a subsequent target picture (Segaert et al., 2011); written completion tasks, in which participants need to complete sentence fragments to produce grammatical sentences (Pickering & Branigan, 1998); picture-matching and description, in which participants listen to previously presented picture descriptions and describe subsequent target pictures (Branigan & McLean, 2016); immediate recall of sentences with participants orally reproducing previously presented sentences (Potter & Lombardi, 1998); and dialogues where speakers align their syntactic structure during a conversation (Branigan, Pickering, & Cleland, 2000)

The syntactic priming phenomenon is well established and its effects are robust in language production research (Pickering & Ferreira, 2008). However, the magnitude of syntactic priming effects varies, and this variation may have several explanations. According to Branigan (2007), the type of task used, the structure under investigation, and the condition of lexical repetition have an impact on the magnitude of syntactic priming effects. Indeed, in Bock (1986) the memory task influenced the processing of primed prepositional-object (PO) and double-object (DO) dative structures by approximately 23% of occurrences, whereas the processing of active and passive structures increased in frequency only by 8%. However, Pickering and Branigan

(1998) used similar PO/DO dative structures, but their results were different from those of Bock (1986). The researchers employed a written completion task to elicit syntactic priming effects and the results demonstrated syntactic priming effects, but their magnitude was weaker in comparison to the magnitude observed in Bock's experiments (1986). Finally, lexical repetition plays a role in the magnitude of syntactic priming effects. Although syntactic priming effects in production occur robustly in the absence of lexical repetition between primes and targets, i.e., effects are not dependent of lexical repetition, the magnitude of syntactic priming effects is enhanced or boosted in the presence of a repeated noun (Cleland & Pickering, 2003) or a repeated verb (Pickering & Branigan, 1998; Segaert et al., 2013).

In light of the above, it can be concluded that syntactic priming effects in language production are well established. These effects have been observed for various syntactic structures as well as have been elicited experimentally employing many tasks. Syntactic priming effects in language comprehension have been underinvestigated in comparison to the number of studies in language production (Branigan, 2007). The next subsection is devoted to these few studies that explored syntactic priming in language comprehension.

4.2.2 Syntactic priming in language comprehension

Early reports on sentence processing in language comprehension were provided by a group of researchers who investigated auditory processing of ambiguous sentences (Carey, Mehler, & Bever, 1970; Mehler & Carey, 1967). Mehler and Carey (1967) presented four groups of sentences each containing ten syntactically homogeneous sentences. A syntactically different sentence, so-called anomalous test sentence, followed each group of ten sentences. For example, the group containing ten sentences like *They are describing events* was accompanied by a test sentence like *They are conflicting desires* where the first two words in every sentence were always the same (*they are*). All sentences were presented auditorily to participants mixed with white noise. Participants had to listen carefully to each sentence and then write it down in the interval before listening to the next sentence. The researchers concluded that participants established expectations in relation to syntactic structures, and when the expectations were violated, participants demonstrated difficulty in perceiving test sentences.

In the study of Carey and colleagues (1970) participants judged sentences true or false in relation to pictures. Stimuli were organized in four sets of five unambiguous sentences like *They are discussing paintings* with the progressive verb structure or like *They are nourishing lunches* with the adjectival structure. Each set was followed by one ambiguous sentence like *They are visiting sailors* that can be interpreted in the progressive sense (people are paying a visit to sailors) or in the adjectival sense (sailors are paying a visit to someone). The results showed that the ambiguity was perceived when sentence interpretation matched picture interpretation and response latencies were shortest when these interpretations did not match, thus indicating clear differences in processing ambiguous sentences based on syntactic expectations.

Since then, syntactic priming in language comprehension has received an additional interest. However, evidence for syntactic priming effects in comprehension has been less consistently observed than in language production (Branigan, 2007). Taking into account that the object of investigation in the present dissertation is syntactic priming during silent sentence reading, it seems rational to devote more attention to studies that explored syntactic priming during *on-line* comprehension and to review their findings. Therefore, several recent and most commonly cited papers are reviewed next. Besides these criteria, the selection of these studies for a review is justified by the fact that they employed different experimental designs.

In an event-related potential (ERP) experiment, Ledoux and colleagues (2007) investigated syntactic priming with lexical overlap between pairs of prime and target sentences. The stimuli were adopted from Pickering and Traxler (2004). A prime sentence had either a reduced-relative (RR) or a main-clause (MC) construction, whereas a target sentence always had the reduced-relative (RR) construction and the same verb as its prime. Therefore, each RR sentence occurred in both conditions: as a prime sentence and as a target sentence, thus functioning as its own control. In addition, as can be seen in the example below, both types of prime sentences were the same up to and including the first verb (the verb *proposed*).

Prime RR: *The speaker <u>proposed</u> by the group would work perfectly for the program.*

Prime MC: *The speaker <u>proposed</u> the solution to the group at the space program.*

Target RR: *The manager <u>proposed</u> by the directors was a bitter old man.*

Thirty adults, native speakers of English, participated in the study. All belonged to the student population and did not report any neurological impairment. Participants performed on either one of the four versions of the experimental task where two factors were manipulated: the type of a prime sentence (RR or MC) and the position of a particular RR sentence (prime or target).

The ERP results showed that RR primes evoked a larger positivity than MC primes did, thus indicating a greater difficulty in processing RR primes in comparison to MC primes.[25] Moreover, the results revealed differential processing of RR target sentences due to the type of the preceding prime. RR targets that were paired with MC primes elicited a greater positivity than when they followed RR primes. Taking into account that the only difference between these two conditions was a syntactic structure, it seems reasonable to assume the facilitating priming effects of RR primes. In addition, the experimental design allowed the researchers to compare reading of RR sentences as a prime and as a target. This comparison revealed no differences in processing, thus dissociating syntactic priming effects from effects of lexical repetition at the verb.

In two eye-tracking experiments, Arai and colleagues (2007) investigated syntactic priming during sentence comprehension. To a large extent, studies that investigated syntactic priming in comprehension were interested in the processing of syntactically ambiguous sentences (Branigan et al., 2005; Ledoux et al., 2007; Noppeney & Price, 2004; Scheepers & Crocker, 2004). However, Arai and colleagues decided to explore the processing of meaning-equivalent syntactic structures, more specifically, ditransitive double-object (DO) and prepositional-object (PO) dative sentences. To this end, they conducted two experiments. In Experiment 1, they investigated whether syntactic priming occurred in the condition of verb repetition across prime and target sentences:

DO prime: *The assassin will send the dictator the parcel.*
PO prime: *The assassin will send the parcel to the dictator.*
DO target: *The pirate will send the princess the necklace.*
PO target: *The pirate will send the necklace to the princess.*

In Experiment 2, primes and targets did not share the same verbs:

DO prime: *The assassin will give the dictator the parcel.*
PO prime: *The assassin will give the parcel to the dictator.*
DO target: *The pirate will send the princess the necklace.*
PO target: *The pirate will send the princess the necklace.*

[25] ERP components reflect electrical brain activity triggered by external stimuli (van Hell & Witteman, 2009). ERP components have either a positive polarity (a positive-going wave, for instance, the component P300) or a negative polarity (a negative-going wave, for instance, the component N400).

The researchers recruited an equal number of participants for both experiments: 32 university students, native speakers of British English. The methodology employed in both experiments was roughly the same as in the study of Scheepers and Crocker (2004). There were two types of stimuli: a written sentence as a prime (DO or PO) that participants needed to read aloud, and a picture accompanied by its corresponding oral description, in which they needed to pay attention both to the picture and to the spoken sentence.

The data from Experiment 1 provided clear evidence for syntactic priming effects during comprehension, when the verb was repeated between primes and targets. In Experiment 2, in which primes and targets did not share the same verb, syntactic priming effects were not detected. Taking together the results from both experiments, Arai and colleagues (2007) made a valuable inference and claimed that syntactic priming during comprehension occurs for the same structures that are used in production studies (Bock, 1986; Branigan, Pickering, & Cleland, 2000; Branigan, Pickering, Stewart, & McLean, 2000; Pickering & Branigan, 1998). In line with production studies, syntactic priming effects were observed when primes and targets shared the same verb; however, they were absent when the verb was different. In other words, syntactic priming effects in language comprehension were completely lexically dependent.

Contrary to the claim that syntactic priming is lexically dependent, i.e., syntactic priming is not observed in the no-verb repetition condition (Arai et al., 2007), Thothathiri and Snedeker (2008a) provide evidence for lexically-independent syntactic priming during spoken language comprehension. The researchers also used semantically equivalent dative sentences: double-object (DO) and prepositional-object (PO) sentences. However, there were two important differences in the design. First, prime and target sentences did not share verb and nouns. Second, instead of using a passive viewing task like in Arai and colleagues (2007), the researchers used an act-out comprehension task to be described next (Thothathiri & Snedeker, 2008a).

In one of the experiments, adult participants saw four shelves with a toy each (two animals and two inanimate objects). In the center, there was a camera that monitored their eye movements. Participants listened to instructions where two sentence fillers were included first, and then two DO or PO prime sentences followed (e.g., a DO sentence *Send the frog the gift*; a PO sentence: *Send the gift to the frog*). The last fifth sentence of a sample block was a target trial either a DO sentence (e.g., *Show the horse the book*) or a PO sentence (e.g., *Show the horn to the* *dog*). In another experiment, participants listened to two voices (female and male) from a computer. A male would tell them stories of his life, in which two last sentences served as a DO or PO prime, whereas a female would give them instructions to act out with their eyes, involving dative sentences as a DO or PO target. In these experiments, eye movements to an animal and an object were monitored in relation to the onset of the first noun for DO and PO targets.

Overall, the results showed that eye movements for target trials were strongly affected by the type of prime trials (DO or PO sentence). In the DO-prime condition, participants processed DO target trials looking more at the animal rather than at the object, whereas in the PO-prime conditions, participants were more likely to look at the object. Therefore, Thothathiri and Snedeker (2008a) had clear evidence for abstract syntactic representations during on-line language comprehension, where prime and target sentence used different verbs and nouns, i.e., demonstrating no lexical dependency.

In addition to the behavioral evidence of syntactic priming in comprehension, Noppeney and Price (2004) were interested in investigating the neural correlates of syntactic priming during silent sentence reading. Twenty-five healthy adults, native English speakers, participated across two experiments: twelve participants in the fMRI experiment, in which the syntactic priming effects were investigated using blood oxygenation level-dependent (BOLD responses as a physiological measure, and thirteen participants in the behavioral experiment, in which reading times were a behavioral measure in a self-paced reading paradigm. In both experiments, participants silently read blocks of nine-word sentences with four possible syntactic forms. Presented within a block of five, sentences were either all with syntactically similar structures or a mixture of syntactically dissimilar structures. The researchers controlled the degree of syntactic ambiguity where in less ambiguous conditions, the boundaries of the clauses were indicated by commas, and in syntactically ambiguous conditions, no commas were used (Noppeney & Price, 2004). The examples of these conditions are presented next.

1. Clause boundary ambiguity

a) Late closure (preferred interpretation): *Before the director left the stage(,) the play began.*

b)Early closure (non-preferred interpretation): *After the headmaster had left (,) the school deteriorated rapidly.*

2. Reduced relative/main clause ambiguity

a) Simple active (preferred interpretation): *The artist left his sculptures to the British Museum.*
b) Reduced relative (non-preferred interpretation): *The child (,) left by his parents (,) played table football.*

The behavioral and fMRI experiments had two different presentation modes. The behavioral experiment did not contain sentence comprehension questions. However, participants' eye movements were monitored in order to confirm that they were paying attention to the experimental sentences. In addition, participants visualized all nine words of a sentence at once on the computer screen and pressed the key bar to trigger the next sentence. In the fMRI experiment, participants saw each word at a time at a fixed pace and brain responses in the neural system underlying sentence comprehension confirmed that participants were processing the experimental sentences.

Behavioral results showed that reading times were significantly faster for the blocks with similar (primed) sentences rather than for the blocks with dissimilar (unprimed) sentences, thus, indicating syntactic priming effects at the behavioral level. In the fMRI experiment, participants' BOLD responses to sentence reading were compared to the ones for false font viewing, and the analysis revealed predominantly left-lateralized activation in the left superior temporal sulcus, middle temporal gyri spreading into the temporal poles bilaterally. Moreover, participants activated the left inferior frontal gyrus (LIFG)/lateral fissure and the right cerebellum during sentence reading. When comparing two conditions (primed and unprimed), the left temporal pole was the only area with significantly more activation for the blocks of dissimilar (unprimed) sentences than with similar (primed) sentences. Therefore, this study provides supporting evidence for syntactic priming effects in comprehension by decreased reading times at the behavioral level and by attenuated responses (repetition suppression effects) in the left temporal pole at the neuronal level.

The available evidence for syntactic priming in comprehension shows that syntactic priming effects are more elusive in comprehension than in production (Tooley & Traxler, 2010). Nevertheless, different measures have been used to detect syntactic priming in comprehension, for instance, picture matching (Branigan et al., 2005), ERPs (Ledoux et al., 2007), eye movements (Traxler, Tooley, & Pickering, 2014), or brain responses (Noppeney & Price, 2004). Moreover, similarly to production studies, different structures have been employed to detect syntactic priming in comprehension, for instance, reduced relative clauses (Ledoux et al., 2007) and PO and DO datives (Arai et al., 2007).

In comprehension studies, syntactic priming is readily detectable in the presence of both syntactic and lexical overlap, whereas, differently from production studies, no significant priming effects are detected in the absence of lexical overlap, particularly without verb repetition (Arai et al., 2007; Branigan, Pickering, & McLean, 2005; Tooley, Traxler, & Swaab, 2009). However, a controversy to this claim comes from studies that reported syntactic priming effects in comprehension when primes and targets had different verbs (Kim, Carbary, & Tanenhaus, 2014; Thothathiri & Snedeker, 2008b; Traxler, 2008). The controversy around syntactic priming effects during comprehension indicates that there is still a need to conduct more studies on syntactic priming in comprehension. Next, I move on to studies on syntactic priming across language modalities.

4.2.3 Syntactic priming across language modalities

One possible explanation for why syntactic priming effects have been less consistently revealed in comprehension than in production can be attributed to the fact that production is all about critical structural choices (Pickering & Ferreira, 2008). In this view, the speaker has the choice about what structure to use, i.e., s/he is free to convert the intended message using different syntactic structures (e.g., an active or passive, a PO or DO dative). This choice is roughly similar to the choice about what words to use. Syntactic priming influences the speaker's decision about which structure to choose. To give an example, for the message stating that a girl was kissing a boy, there are at least three possible structures available to the speaker: an active transitive *The girl kissed the boy*, a passive transitive *The boy was kissed by the girl*, emphasizing the role of the patient of the action, or a cleft sentence *It is the girl that kissed the boy,* using a relative clause to create emphasis on the agent of the action (Segaert et al., 2012).

On the other hand, in language comprehension an individual does not make such important decisions about what structures to use. This individual receives the structure previously determined by the interlocutor as an input and the goal is to process and interpret it correctly. In the examples above, the words *girl, kissed* and *boy* can take different positions in the sentence that intuitively implies different meanings of the sentences. Although when comparing sentences like *The girl kissed the boy* and *The girl was kissed by the boy* where the order of the words is the same, the two sentences have different structures and meanings. Thus, at a certain point during sentence processing some ambiguous interpretation may take place as information is received incrementally and it is the comprehender who needs to make decisions about the sentence structure in order to understand the message.

Several studies have addressed this issue and reported consistent behavioral syntactic priming effects across language modalities: from comprehension to production (Bock, Dell, Chang, & Onishi, 2007; Branigan, Pickering, & Cleland, 2000), and from production to comprehension (Branigan et al., 2005). Bock and colleagues (2007) used the materials, procedures, and designs similar to Bock and Griffin (2000), though without the repetition of auditory presented sentences. In one of the experiments, there were short- (Lags 1 and 2) and long- (Lags 4 and 10) lag conditions where lags corresponded to the number of intervening sentences between prime and target sentences. Participants looked at experimental pictures and heard their corresponding descriptions as a prime. Half of the experimental pictures corresponded to transitive sentence structures (passives and actives) and for the other half, PO/DO dative sentence structures were used. After listening to the description of a picture, participants described a subsequent picture in one sentence using either transitive structures or dative structures. The results revealed syntactic priming in picture descriptions across multiple intervening sentences, thus, emphasizing the evidence for cross-modal syntactic priming. Moreover, Bock and colleagues (2007) claim that syntactic priming does not show modality dependence as the magnitude of priming effects from comprehension to production is comparable to the ones observed from production to production. Branigan and colleagues (2005) investigated syntactic priming from production to comprehension; more specifically, they were interested in whether picture description produced by participants could prime description-picture matching. For production trials (prime), participants read a verb that they needed to use in the subsequent description of a picture. The description was based either on a high-attached structure where an agent using an object was performing an action on a patient or a low-attached structure where an agent was performing an action on a patient holding an object. For comprehension trials (target), participants read an ambiguous sentence that could be interpreted either as a high- or low-attached structure, and they had to match the description of a sentence to one of the two presented pictures. The results showed that participants were more prone to adopt the high-attached interpretation in a description-picture matching (*target*) after producing a picture description with the high-attached interpretation (*prime*) with the same verb. In other words, prior production of a particular structure influenced subsequent comprehension of an ambiguous structure. These findings also provide additional support to the idea that common syntactic representations are activated during comprehension and production (Branigan, Pickering & Cleland, 2000; Pickering & Garrod, 2004).

In addition to the discussion about the contrast in syntactic priming effects in comprehension and production, one may argue that there may exist two functionally separate systems responsible for comprehension and production processes. This idea has strong grounds in developmental studies that provide evidence that children can interpret more complex sentence structures than they can produce (Villiers & Villiers, 1979). In addition, the early reports of Broca's and Wernicke's aphasic patients constituted strong evidence for the idea of two separate systems carried on by two distinct anatomical areas. To clarify this, Broca's aphasia is referred to a condition when damage to Broca's area leads to impaired production, but relatively intact comprehension. Wernicke's aphasia is a stark contrast to Broca's aphasia. Wernickes' aphasia arises from lesions to Wernicke's area that provokes impaired comprehension, but does not affect production (Dehaene, 2009). However, considerable evidence has also been provided against the idea of brain labor division between production and comprehension, showing that both language modalities engage the combinatory network of brain areas, employing Broca's and Wernicke's areas to a certain extent, in addition to other regions (Poeppel, Emmorey, Hickok, & Pylkkänen, 2012)

As the literature has not been conclusive about the nature of the system subserving production and comprehension processes, Segaert and colleagues (2012) ran an fMRI experiment to address this issue. They investigated the neurobiological system for coding and processing syntactic representations in language comprehension and language production. The researchers recruited 24 adult participants, native speakers of Dutch. The stimulus material contained photographs and auditory sentence descriptions of transitive events like *kissing, helping*, thus, involving the agent and the patient of these actions.

During comprehension, a picture-matching paradigm was used. Participants saw grayscale photographs accompanied by auditory description with either an active or passive voice sentence as well as intransitive sentences as fillers. For attentional control, there were descriptions that did not correspond to the photograph in 10% of trials. During production, participants described colored photographs using the previously presented verb, first naming the actor depicted in green, then the actor depicted in red. In other words, they were forced to choose a particular structure (active or passive) following the stop-light paradigm

(Menenti, Gierhan, Segaert, & Hagoort, 2011).[26] Segaert and colleagues (2012) controlled the syntactic structure and the processing modality where the syntactic structure could be the same (active-active or passive-passive) as well as the modality (comprehension-comprehension or production-production) or the syntactic structure could be different (active-passive or passive-active) as well as the modality (comprehension-production or production-comprehension). The verb was always repeated between prime and target sentences.

Analyzing behavioral performance during comprehension and production, the results demonstrated that participants performed equally well in both modalities: 92% of the trials were detected as mismatch trials in the comprehension task, and 96% of the trials responded correctly in the production task. Analyzing brain responses, the researchers observed facilitated processing due to syntactic repetition within and across modalities. The results revealed several regions showing repetition suppression effects to primed syntactic structures: the left inferior frontal gyrus (BA45), left middle temporal gyrus (BA21), and bilateral supplementary motor area (BA6). In other words, these regions demonstrated less activation for sentences with the same structure rather than with a different one. Overall, this study provides evidence for facilitation effects of syntactic priming in the brain within and across language modalities. In addition, the findings support the idea of a shared neuronal system for syntactic processing during language comprehension and language production.

Having provided evidence on healthy adult populations sharing common syntactic representations during comprehension and production at the behavioral and neuronal levels, it seems commonsensical to review studies that have investigated syntactic priming in special populations. The next subsection reviews some of these studies.

4.2.4 Syntactic priming investigated in special populations

Traditionally, syntactic priming studies have focused on investigating syntactic processing in healthy adult populations (Bock & Griffin, 2000; Branigan, Pickering, & Cleland, 2000; Hartsuiker & Kolk, 1998; Segaert, Menenti, Weber, & Hagoort, 2011; Segaert, Wheeldon, & Hagoort, 2016). However, syntactic priming has also been reported in

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[26] In tasks, which employ the stop-light paradigm (also called the traffic-light paradigm), participant are instructed to describe the color-coded photographs using the presented verb and naming the green actor before the red actor (Menenti et al., 2011).

special populations like healthy young children (Branigan & McLean, 2016; Branigan, McLean, Thatcher, & Jones, 2006; Branigan & Messenger, 2016; Peter, Chang, Pine, Blything, & Rowland, 2015; Savage, Lieven, Theakston, & Tomasello, 2003; Tomasello, 2000), children with specific language impairment (Garraffa, Coco, & Branigan, 2015; Marinellie, 2006) and impaired adults (Atchley, Story, & Buchanan, 2001; (Hartsuiker & Kolk, 1998b). To the best of my knowledge, no study has investigated syntactic priming effects in children with developmental dyslexia. Here, these populations (i.e., healthy young children, impaired adults, and dyslexics) are treated as special because they request additional attention and caution during experimental settings and procedures (Branigan, 2007).

Evidence for syntactic priming in children remains controversial. Some studies report early acquisition of abstract syntactic representations (Branigan et al., 2006; Huttenlocher, Vasilyeva, & Shimpi, 2004). Branigan and colleagues (2006) conducted three experiments with children between 2;6 and 4 years based on a "snap" game. The experimenter and a child alternatively described pictures with colored objects. The experimenter described half of the pictures using a determiner-adjective-noun structure (e.g., *a blue cat*) and the other half using a noun-relative clause structure (e.g., *a cat that`s blue*). Their results suggested that children as young as 2;6 years could be primed to produce structures merely by listening to a single exemplar of a structure. Thus, these results corroborate the assumption of abstract syntactic representations in young children.

In this line, interesting insights into the development of children's abstract syntactic representations have also been provided by Savage and colleagues (2003). Children at the ages of 3-, 4- and 6 years were required to describe target pictures shortly after repeating either an active or a passive prime sentence. For half of situations, there was a high lexical overlap between prime and target trials, and for the other half, there was very low lexical overlap. The results showed that only 6-year-old children demonstrated reliable priming effects without a repeated lexical content, whereas 3- and 4-year-old children demonstrated lexical priming only. Thus, these results suggest young children develop abstract syntactic representations gradually during the preschool years.

Tomasello (2000) reviews a number of observational and experimental studies that explored child language acquisition. Based on the findings, the researcher strongly advocates for a lack of abstract syntactic competence in children at younger ages. Young children`s syntax is based on individual (concrete) lexical items, i.e., item-based

(Tomasello, 2000). In other words, if a child uses a particular sentence structure with one lexical item, the prior production of that structure will not facilitate subsequent production with a different lexical item.

In order to learn more about language processing in children with specific language impairment (SLI), Garraffa and colleagues (2015) explored syntactic priming in this special population aiming to see whether children with SLI exhibit failures in developing appropriate syntactic representations. The researchers investigated Italian pre-school children with SLI on the production of subject relative clauses (SRc). The syntactic priming paradigm was presented in the form of a picture-matching task. The experimenter placed a set of picture cards face-down, selected one card and described a picture with a bare noun or an SRc and this constituted the *prime*. Children listened to the description and then picked up a subsequent card to describe. Their production constituted the *target*. The results showed that children with SLI produced SRc after listening to SRc with the same or different lexical content. The magnitude of syntactic priming effects was compatible with the control group; however, cumulative priming effects were smaller for children with SLI. In light of these findings, the researchers proposed that children with SLI had abstract syntactic representations facilitated by prior exposure, but they showed evidence for a deficit in implicit learning mechanisms (Garraffa et al., 2015).

Syntactic priming has also been investigated in adults with some kind of deficiency (Atchley, Story, & Buchanan, 2001; Hartsuiker & Kolk, 1998b). Taking into account that Broca’s aphasics demonstrate a reduced complexity of syntactic structure, Hartsuiker and Kolk (1998b) were intrigued whether this special population would benefit from syntactic priming effects during language production. The researchers exposed 12 Broca's aphasics and 12 controls, native speakers of Dutch, to three different conditions: spontaneous speech, picture description without priming, and picture description with priming. The experimenter elicited their speech with the help of 27 pictures for transitive sentences (actives and passives) and 27 pictures for dative sentences. The main findings revealed that Broca’s aphasics demonstrated syntactic priming effects for both passive transitives and datives, whereas controls failed to do so. No syntactic priming effects in controls were explained by a small number of participants. Moreover, the pattern found in Broca’s aphasics suggested a lack of strategy involvement in priming effects because participants were explicitly instructed to reuse the syntactic structure of the previously presented sentence in the description of pictures, thus obtaining evidence for an unconscious, automatic, and facilitatory process rather than strategic. In the condition with syntactic priming, Broca's aphasics were able to produce relatively complex sentences like passives that they did not, however, produce in spontaneous speech.

Overall, it can be concluded that syntactic priming effects in special populations (children and Broca's aphasics) are compatible with the control group (healthy children and adults). Thus, it is assumed that syntactic priming is an effective way to investigate the nature of syntactic representations in these special populations. Importantly, syntactic priming effects may be helpful for aphasics to overcome their limited computational resources, at least temporarily, thus implying potential benefits for aphasia therapy.

To conclude, during production or comprehension a language user needs to access and process abstract syntactic representations in order to create and express new utterances and process spoken or written utterances, respectively. To understand how a language user does this and what mechanisms underlie sentence processing, the syntactic priming paradigm has been extensively employed (Bock, 1986; Branigan, 2007; Segaert et al., 2012). In light of the reviewed literature on syntactic priming, it can be assumed that the syntactic priming paradigm is a valuable tool to tap into this issue. On the basis of cumulative evidence for syntactic priming in language comprehension and language production, it is essential to understand the mechanisms behind syntactic priming. The following section presents two influential theoretical accounts that offer distinct views for the mechanism responsible for syntactic priming: a residual activation theory (Pickering & Branigan, 1998) and an error-based implicit learning theory (Chang et al., 2006; 2000).

4.3 THEORETICAL ACCOUNTS OF SYNTACTIC PRIMING EFFECTS

To date, syntactic priming effects have been demonstrated in both language production and language comprehension. However, the theoretical explanation of the nature of syntactic priming is still a matter of debate. So far, two hypotheses have been proposed: a residual activation theory (Pickering & Branigan, 1998) and an error-based implicit learning theory (Chang et al., 2006; 2000). These two theoretical proposals present a distinct view on the mechanisms driving syntactic priming and provide different predictions for its effects. Therefore, these proposals are often viewed as contradictory (Bock & Griffin, 2000). The main assumptions of these two theories are presented next.

The residual activation theory emphasizes the role of lexical representations in syntactic encoding and decoding (Cleland & Pickering, 2003; Pickering & Branigan, 1998). More specifically, it accounts for evidence when syntactic priming is enhanced by lexical repetition, i.e., prime and target sentences share the content word (a lexical entry). Following this assumption, a lexical entry represented in the mental lexicon includes a lemma stratum that contains syntactic information, and a word-form stratum that encompasses morphological and phonological information. Pickering and Branigan (1998) presented an extended version of the model of the lemma stratum of Roelofs (1992, 1993) to which they added the existing category (e.g., noun, verb) and gender (feminine, masculine) nodes, the nodes related to other features and the nodes responsible for combinatorial information.

According to this lexically based model, when the speaker produces a sentence, for example, with a double-object structure such as *John gives the dog a bone*, the lemma *give,* nodes encoding features like present tense, singular, third person, and the combinatorial node of two noun phrases (*NP*) are activated. Thus, Pickering and Branigan (1998) argue that category, feature, and combinatorial nodes are directly connected to the lemma nodes. This supports the idea that combinatorial information refers to a property of a verb lemma, and not to a property of a distinct representation of a verb.

According to Pickering and Branigan (1998), this model explains the syntactic priming phenomenon as residual activation of combinatorial and lemma nodes and the link between them. The researchers point out that activation of these nodes and the link between them faints gradually, but it does not disappear at once. There is still some residual activation that leads to facilitation in producing a consecutive sentence. Thus, for example, if the speaker needs to produce a sentence with the meaning of Maria giving a present to the mother having been previously exposed to a sentence with a double-object dative construction, and not a prepositional one, then the combinatorial nodes *NP, NP* of a double-object construction will be faster activated. Thus, the speaker will be more likely to produce *Maria gives the mother a present*. In other words, the preceding sentence with this particular structure influences the speaker's subsequent choice of a structure to express a message. Moreover, Pickering and Branigan (1998) claim that syntactic priming will take place even when, for example, the lemma *give* varies in its features, for example, tense and number.

Given that different lemmas, for instance, the verbs *give* and *send,* share the same combinatorial nodes, Pickering and Branigan (1998) also propose that some priming between these verbs will burst forth, though the magnitude of priming will not be the same as in the presence of the repeated verb. They suppose that when using the same verb (the head word) residual activation of the combinatorial node, the verb node and the link between them will likely have a preference for the same combinatorial node. Therefore, syntactic priming is boosted through the repetition of a lexical item between the prime and the target, the phenomenon known as the *lexical boost effect* (Pickering & Ferreira, 2008; Traxler, 2008). However, if different verbs are used instead, i.e., no lexical repetition, only residual activation of the combinatorial node that these verbs share can lead to priming. In accord with Pickering and Branigan (1998), this explains why the magnitude of priming between different verbs is generally weaker than between the same verb.

Pickering and Branigan (1998) conducted several experiments in support of the residual activation account. Using a written completion task, the researchers investigated syntactic priming in PO or DO dative structures in the condition of verb repetition and no verb repetition. They found syntactic priming effects when the prime and the target had different verbs, but these effects were stronger when the verb was repeated. Additionally, the researcher investigated syntactic priming in relation to tense, aspect, and number of the verb that was the same or different between the same sentence fragments. Interestingly, they found that syntactic priming occurred irrespective of the verb features indicating that it is the verb's lemma, which encodes syntactic information, and not a particular form of the verb.

Additionally, according to the residual activation account, syntactic priming is time limited and is short lasting (Branigan, Pickering, & Cleland, 1999). A short-term memory limitation explains the mechanisms that cause syntactic priming. However, it is still questionable how the activation of syntactic structures decays, whether this is simply a question of time or the activation of one structure may be alternated by the activation of another structure (Pickering, Branigan, Cleland, & Stewart, 2000). Importantly, the residual activation account cannot explain evidence of long lasting priming effects that have also been shown in the literature (Bock & Griffin, 2000; Branigan, Pickering, Stewart, et al., 2000; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Kaschak, Kutta, & Schatschneider, 2011; Vasilyeva, Huttenlocher, & Waterfall, 2006). To account for long lasting effects, Pickering and Branigan (1998) suggest that there should be a complementary mechanism at work that is worth further investigation.

The alternative account of syntactic priming, an error-based implicit learning theory proposed by Chang and colleagues (2006; 2000) addressed the durability of priming and explains a long-term component of syntactic priming as a form of implicit learning. Following this account, syntactic priming usually takes place when an individual has little awareness and does not make much explicit and conscious effort on language processing that is often interpreted as a form of procedural or implicit learning.

Agreeing with Seger (1994), Chang and colleagues (2006; 2000) adopted her definition of implicit learning which is associated with incidental learning of fairly complex and abstract information resulting in knowledge. This knowledge is not fully accessible to consciousness. In the case of syntactic priming, syntactic knowledge is at stake. The evidence for unconscious access to syntactic representations comes from the study with patients suffering from anterograde amnesia (Ferreira, Bock, Wilson, & Cohen, 2008). The findings showed that despite having severely impaired explicit memory, participants with amnesia exhibited syntactic priming to the same extent as normal speakers, thus providing additional evidence to the contribution of procedural memory to syntactic priming.

The explanation of syntactic priming in terms of implicit learning has roots in a connectionist model of sentence production with the dual-path architecture (Chang et al., 2006). According to the dual-path model, the ability to use words in novel sentences is based on one pathway where a mapping between the meaning and the word occurs (the meaning system). The other pathway is related to organizing words in a particular position to form a sentence (the sequencing system). Combinatorial properties of this model can account for the acquisition of syntactic structures even in aphasics, whose procedural memory is intact (Ferreira et al., 2008).

Accepting the idea of abstract syntactic representations, Chang and colleagues (2006; 2000) adapted a simple recurrent network (SRN) conceived by Elman (1990) to a sentence production task. An SRN involves three layers: input, hidden, and output. These three levels interact sequentially where the input units activate the hidden ones and these, in turn, activate the output units. In line with an SRN, Chang and colleagues (2006) argue that syntactic abstractions are the product of learners' predictions about the upcoming information and if these predictions are erroneous, the system responsible for predictions suffers some changes (connection adjustments) that entails an error-based learning.

However, Chang and colleagues (2006) acknowledge that the sequencing system cannot rely solely upon an SRN because it will not be able to account for the use of the word concept in a novel structural configuration, for example, the verb *zeta-jonesed.* Given that, Chang and colleagues (2006) augmented an SRN with the meaning system which is responsible for transmitting a message. The message involves concepts and event roles, and the binding between them. Thus, in the case of the verb *zeta-jonesed,* there is a generalization of the proper name Zeta-Jones to the new thematic role where the verb refers to eating vegetarian food like the actress Catherine Zeta-Jones. In other words, the same concept has different roles in a sentence (agent/patient or action).

The main assumption of the error-based implicit learning account is that syntactic representations are independent of lexical content (Chang et al., 2000). The processes associated with syntactic priming occur outside the mental lexicon. According to Chang and colleagues (2000), syntactic structures are built first based on their abstract representations, and then information about words (lemma) is added. Therefore, this syntax-first assumption suggests that syntactic priming effects should occur in the absence of lexical repetition. This division of labor between the sequencing and meaning systems gives insight into human language acquisition and language change, especially in aphasias like agrammatism and anomia.[27] The assumption of a lexically independent syntactic priming goes in contrast with the residual activation account, which claims that syntactic priming is lexically mediated (Cleland & Pickering, 2003; Pickering & Branigan, 1998).

Additionally, the implicit learning theory of syntactic priming can explain evidence when syntactic priming effects are substantially enhanced by less preferred/frequent syntactic structures than by more preferred/frequent ones, for examples, a DO structure versus PO structure (Bernolet & Hartsuiker, 2010) or passive voice sentence structure versus active voice sentence structure (Bock, 1986; Segaert et al., 2014) known as the *inverse-preference effect.* The account of syntactic priming as a form of error-based learning predicts larger errors for less preferred structures which in turn are associated with larger changes (adjustments) in internal syntactic representations and larger effects on structure choice.

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[27] Agrammatism is a disorder of syntax, i.e., the tendency to speak telegraphically without using function words like prepositions. Anomia is a disorder of word retrieval (Hier et al., 1987).

Put another way, novel or less familiar structures require greater effort and learning in comparison to frequently used ones (Ferreira & Bock, 2006).

Furthermore, Chang and colleagues (2006) claim that adjustments due to implicit learning should have relatively long effects. Changes to connection weights between a particular message and a particular structure are available until the processor finds a similar message with an alternative structure. Therefore, the implicit learning account predicts long-lasting syntactic priming effects where a slow decay may be due to time or the number of intervening sentences between a prime and target sentence. Indeed, the longevity of syntactic priming effects have been evidenced in many studies (Bock & Griffin, 2000; Branigan, Pickering, Stewart, et al., 2000; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Kaschak, Kutta, & Schatschneider, 2011; Vasilyeva, Huttenlocher, & Waterfall, 2006).

The implicit learning account has also been defended by Jaeger and Snider (2007). The researchers acknowledge that when processing a sentence, a language user implicitly learns something about its structure. Following Jager and Snider (2007), when a language user processes a low-frequency structure, the probabilistic distribution of this structure is updated and the probability of a posteriori reuse increases. In other words, syntactic priming plays a role in monitoring and updating the distribution of the most recently used structure.

It is worth highlighting that distributional frequencies determine the relative accessibility or ease of processing associated with a particular structure (Roland, Dick, & Elman, 2007). For instance, there are low-frequency structures like passives and high-frequency structures like actives, where high-frequency structures are relatively easy to access and to process due to everyday use in comparison to low-frequency structure. High-frequency structures become overlearned, thus being always available in the system for a language user. Based on the evidence for greater syntactic priming effects for less preferred or frequent structures, it can be assumed that the syntactic system is flexible enough to support constant updates in the probability distribution when preceded by surprisal prime. The term *surprisal* is associated with the inverse of probability (Jaeger & Snider, 2007). Moreover, the magnitude of syntactic priming is inversely correlated with the degree of preference (Ferreira & Bock, 2006).

The assumption of prime surprisal is consistent with the view that the syntactic system is probabilistic in nature and through syntactic priming, a language user learns the probabilistic distribution of a particular structure by updating his or her preferences (Jaeger & Snider, 2007). The probability of the structure use depends on the context. When a language user is exposed to a low-frequency structure like passive voice that also a less expected structure, his or her surprisal sensitivity to this structure will be associated with an increase in the probability of repetition of this structure later on. By priming, the probability of the distribution of this structure is maintained and, as a result, this structure becomes more salient in the syntactic system. This would support the implicit learning account where experience with infrequent or less preferred structures may result in a facilitated processing of these structures later on.

In addition to the surprisal-sensitivity property of syntactic priming, Jaeger and Snider (2007) state that if effects are long lasting, they may be cumulative. The cumulativity property of syntactic priming would also support the implicit learning account. If syntactic priming effects are related to the distribution of probability, it is expected that these effects go beyond the most recently used syntactic structure. More specifically, the cumulativity property predicts that a prime sentence has an impact not only on a subsequent structure, but it should reach more distant targets. Indeed, there is consistent evidence for cumulative effects of syntactic priming (Hartsuiker & Westenberg, 2000; Kaschak, Kutta, & Coyle, 2014; Kaschak et al., 2011). For instance, Kaschak and colleagues (2011) observed long lasting cumulative effects of syntactic priming in a written completion task with double-object or prepositional object structures. The researchers found that performance on the first session affected performance on the second session that took place one week later.

Based on the above review of the two theoretical accounts of syntactic priming, I can conclude that they make contradicting claims about the existence of a lexical boost and long-term priming effects. The residual activation account explains the lexical boost effect, but not the longevity of syntactic priming. On the other hand, the error-based implicit learning account explains the longevity of syntactic priming, but not the presence of the lexical boost. Therefore, each of these accounts can only partially explain evidence from studies on syntactic priming. An alternative explanation can be that long-term priming effects may reflect implicit learning mechanism, whereas short-term priming effects may rely on explicit-memory processes (Ferreira & Bock, 2006).

To conclude, syntactic priming seems to have multiple functions (Ferreira & Bock, 2006). Based on long lasting effects, implicit learning is one of them and the most valuable. An individual implicitly learns syntactic structures as these are used more often (Chang et al., 2006). Interestingly, learning is more evident when an individual deals with infrequent syntactic structures, the so-called inverse frequency or surprisal effect (Jaeger & Snider, 2007). Additionally, syntactic priming contributes to ease and fluency in processing syntactic structures. Reduced response latencies due to syntactic priming are reported consistently (Corley & Scheepers, 2002). Curiously, an individual may also implicitly learn syntactic information from an interlocutor in order to align understanding (Garrod & Pickering, 2009). For instance, an individual starts to use the same syntactic structures as his or her interlocutor to describe similar situations. It is important to point out that these features of syntactic priming have been shown both in language comprehension and language production as well as across language modalities, thus suggesting that comprehension and production processes are interwoven (Pickering & Garrod, 2013).

With the aim to enrich understanding of syntactic priming in comprehension, in the present dissertation two behavioral studies and one fMRI study were conducted. The common principles of the experimental design employed in the three studies are presented next.

4.4 PRINCIPLES OF THE EXPERIMENTAL DESIGN

The three experiments reported in the present dissertation have the same principles concerning the experimental task – a syntactic priming during comprehension task. However, each experiment has its own specificity. The objective of this section is to explain the general design of the syntactic priming experiments carried out for the purposes of this dissertation.

In the syntactic priming paradigm, participants receive written input with the idea that their processing of a specific syntactic structure will be facilitated by previous processing of the same structure. This facilitation – manifested in terms of faster reaction times and more accuracy in processing – is known as syntactic priming. Given that the magnitude of syntactic priming effects is stronger for difficult and infrequent sentence structures, the experiments carried out investigated syntactic priming of passive sentences. Moreover, syntactic priming was additionally enhanced by the repetition of the main verb.

Half of the experimental sentences had the passive voice structure of the experimental sentences had the passive voice structure (e.g., *The bag was bought by the girl* with Patient-Auxiliary verb-Main verb-by-

Agent structure). In order to minimize the likelihood that participants might understand the purpose of the experiment, the other half of the sentences were filler sentences. In turn, filler sentences were equally divided between active sentences with transitive verbs (e.g., *The girl bought the bag* with the Agent-Verb-Patient structure) and active sentences with intransitive verbs (e.g., *The student slept few hours* with the Agent-Verb-Complement structure). Passive sentences and filler sentences were presented in mini-blocks varying from 2 to 7 sentences. In each mini-block, primes and targets had both structural and lexical overlap at the verb. Due to the need to insert mini-blocks with filler sentences between mini-blocks with passive sentences, the presentation of the experimental list was not randomized automatically. Pseudo-random lists were created instead in order to ensure that mini-blocks with passive sentences did not occur consecutively and there was always a mini-block with filler sentences between them. To control the participants' attention, yes-no comprehension questions were included with half corresponding to the correct answer and the other half corresponding to the incorrect answer.

The experimental task implemented the center non-cumulative self-paced reading paradigm. First, a fixation cross appeared in the center of the screen for a fixed time before every sentence. After this fixed interval, the first word of a sentence replaced the fixation cross. The following words of a sentence appeared on the screen after pressing the space bar, thus, substituting the previous one (Figure 4.1).

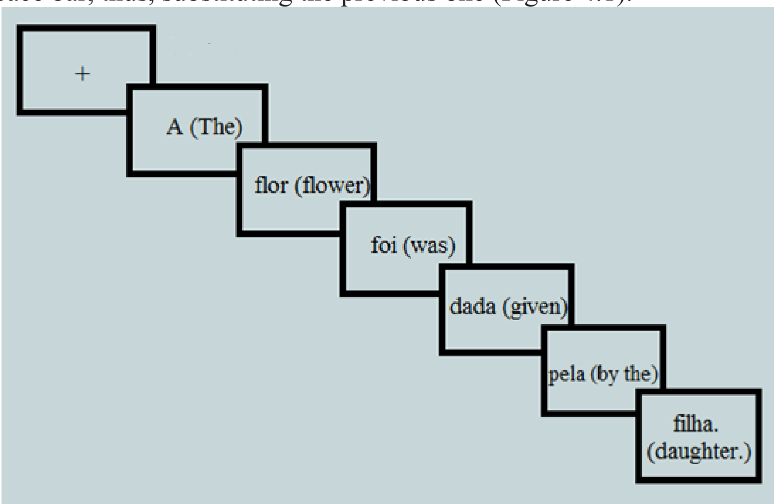

Figure 4.1. General experimental design of a passive sentence presentation.

Although the presented syntactic priming paradigm had the same principles for all three studies, some issues were adapted due to the circumstances of data collections as well as participants. In this dissertation, two studies were conducted with dyslexic children, native speakers of Brazilian Portuguese, and one study was conducted with dyslexic adults, native speakers of English. The discrepancies between these studies are described in the method section of each study in the subsequent chapters. As mentioned above, the syntactic priming paradigm adopted the active-passive alternation. The next section aims at presenting structural and categorical aspects of the passive voice structure as well as differences in the structure between the languages

4.5 STRUCTURAL AND CATEGORICAL ASPECTS OF PASSIVE VOICE

As informed in the previous section, the present dissertation investigated on-line processing of passive sentences, whereas active sentences served as fillers. The passive voice was central in this investigation because this structure is considered to be more complex for comprehension due to its non-canonical word order and is of less frequent use in comparison to the active voice structure (Grodzinsky, 1986; Jaeger & Snider, 2007).

Before discussing the main aspects of the passive voice structure, it is important to state that traditionally, there are three basic categories of verbal voice: active, passive, and reflexive (middle) (Fox & Hopper, 1994). In the active voice sentence (e.g., *The woman kissed the girl)*, the agent (the performer of the action) performs the verbal action toward the patient (the recipient of the action). In the passive voice sentence (e.g., *The girl was kissed by the woman*.), the patient receives the verbal action of the agent. In the reflexive voice sentence (e.g., *Maria dressed herself)*, the action is reciprocal, i.e., the agent is both performing and receiving the verbal action. The passive voice structure is further discussed in more detail.

Passive voice is assumed to be a complex structure due to its semantic, pragmatic and syntactic characteristics. As for the semantic characteristic, thematic roles are assigned to the lexical items which participate in the formation of passive sentences: the agent as the performer of the verbal action and the patient as the recipient of the verbal action. With respect to the pragmatic characteristic, passive sentences are associated with high topicality of the patient and low topicality of the agent or non-topicality when the agent is omitted (agentless passive structures). Regarding the syntactic characteristic, the patient assumes the role of subject and the agent of the verbal action assumes the role of object, thus involving non-canonical word order where the arguments exchanges positions in a sentence.

In the classical literature on acquisition and processing of the passive structure, four types of passives are identified: actional versus non-actional (Maratsos, Fox, Becker, & Chalkley, 1985); verbal versus adjectival passives (Fox & Grodzinsky, 1998); reversible versus non-reversible (Slobin, 1985), and long versus short passives (Horgan, 1978). The distinction between each type of passives is presented next.

The first type of passives, actional versus non-actional, is attributed to the semantic property of the verb (Maratsos et al., 1985). Actional verbs are related to actions, like buying, hitting, kissing (example 1), whereas non-actional verbs, also called psychological verbs, are associated with states of the mind, like hating or loving, or perception, like seeing and hearing (example 2).

1) *The bag was bought by the woman.*

2) *The photo was seen by Mary.*

Maratsos and colleagues (1985) conducted a number of experimental studies with children between the age of four or five on passive structure comprehension and concluded that many children have a capacity to understand passive sentences with action verbs like in example 1 better than non-actional ones like in example 2. The essence of their argument is that acquisition of the passive structure is strongly related to the degree of transitivity of verbs, i.e., their semantic characteristic (Maratsos et al., 1985). With the passage of years, extensive evidence was provided in support of the delay in acquisition of the passive structure with non-actional verb known as the Maratsos effect (Fox & Grodzinsky, 1998).

The second type of passives, verbal versus adjectival passives, are exemplified in sentences 3 and 4. Verbal passives imply an interpretation of the verbal action as in example 3, whereas adjectival passives propose an interpretation of the state resulting from the verbal action, rather than the action itself and are not accompanied by a *by*-phrase as in example 4.

3) *The window was broken by the man.*

4) *The window is broken.*

Verrips (1996) tested comprehension of verbal and adjectival passives in Dutch children within a wide range of ages. The researcher concluded that children older than 5 years interpret passive participles as verbs and not as adjectives; however, no firm conclusion was reached for younger age groups, suggesting that younger children adopt an adjectival interpretation of passives until the age of 5 (Verrips, 1996). These findings are in line with the Maturation hypothesis as an explanation for the delay in verbal passive comprehension or production (Fox & Grodzinsky, 1998). By this hypothesis, it is suggested that children are unable to interpret verbal passives before the relevant age and this ability is related to biological maturation.

The third type of passives, reversible versus non-reversible, is associated with a semantic property of the agent and patient arguments (Slobin, 1985). Sentences in example 5 constitute reversible passives where the patient and agent can be interchanged, i.e., both sentences are semantically correct. In contrast, example 6 is a non-reversible passive because the nouns *present* and *Maria* cannot exchange positions and compose a semantically appropriate sentence. Thus, only transitive verbs can be used in reversible passive sentences.

5) *Maria was hugged by John* and *John was hugged by Maria*.

6) *The present was hugged by Maria.* But not **Maria is hugged by the present.*

According to Slobin (1985), reversible passives are more difficult for comprehension than non-reversible passives because in reversible passives both arguments (the agent and the patient) can be interpreted as the agent of the action. In example 5, both nouns *Maria* and *John* can perform the action of hugging, whereas in example 6, only the noun *Maria* can perform this action in relation to the inanimate object. The study of Sim-Sim (2006) with four, six and nine year old children, native speakers of Portuguese, showed that six-year-old children still demonstrated difficulties in understanding reversible passives. Only nine year-old children showed a level of comprehension compatible with adults, with 77% of correctness.

Finally, the fourth type of passives, long (or untruncated) versus short (or truncated) passives, is associated with the presence of a by-phrase (Horgan, 1978). A long passive sentence contains a *by*-phrase like in example 7, whereas there is no *by*-phrase in a truncated sentence like in example 8.

7) *The shop was opened by the owner*.

8) *The shop was opened.*

In the study conducted by Horgan (1978), children from 2 to 13 years old described pictures. The researcher was interested in children's spontaneous production of passives. The findings revealed that children produced more short passives than long passives with a by-phrase. Children younger than 6 years produced about 10% of long passives. In addition to these findings, Horgan (1078) concluded that children do not treat short passives in the same way as long passives because their interpretation of short passives is initially compatible with an interpretation of stative (or adjectival) structures.

Overall, taking into account the general aspects of passives, i.e., actionality, reversibility, truncation, and length, the following major empirical findings from the studies on the passive have been reported (Villiers & Roeper, 2011). First of all, children's acquisition of passives is delayed in comparison to actives and children younger than 6 years do not have a complete control in using passives. Moreover, the ability to comprehend passives is acquired before the ability to produce passives. In addition, children experience more difficulties with non-actional passives than with actional ones. In a similar vein, long passives with an overt *by*-phrase are more problematic for children than short passives (without a *by*-phrase).

Regarding the experimental stimuli used in the studies, passive sentences had the structure *be + participle* followed by a *by*-phrase (non-truncated). In addition, there were reversible and non-reversible passive sentences, with actional and non-action verbs. The present dissertation reports two studies that were conducted with dyslexic and non-dyslexic children, native speakers of Brazilian Portuguese (BP). Taking into account that the youngest participant was 9 years old, it was expected that children would be familiar with the types of passives used in the experimental task. Moreover, the dissertation includes a third study conducted with dyslexic and non-dyslexic adults, native speakers of British English.[28] Taking into account that there are some commonalities as well as some discernible differences between the passive structure in BP and English (Azevedo, 1980), it seems reasonable to address this issue next.

A description of passive sentences in English and Portuguese is presented in the work of Azevedo (1980). The researcher compares the passive structure between these languages and provides evidence for the complexity of passive structures in BP. First of all, in BP, the definite article agrees with the noun in gender (feminine or masculine) and number (singular or plural), for example, *a casa, o cachorro, os livros*, whereas English has neither gender nor number agreement, for example,

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[28] Study III included in this dissertation is the result of a cooperation with Professor Katrien Segaert and two undergraduate students of the School of Psychology from the University of Birmingham, the UK., by means of a Newton Fund grant to Professor Mailce Mota (CONFAP/FAPESC-Newton Fund 2016).

the house, the dog, the books (translation of the examples in BP). The auxiliary verb *ser* in BR and *to be* in English agree with the subject (the patient of the verbal action) in number, for instance, *a casa foi, os livros foram* in BP and *the house was and the books were* in English. In English, the participle in a passive sentence does not agree in gender and number with the subject. On the other hand, the BP participles must agree in gender and number with the subject. For example, in English, the participle does not change its form: *the house was bought, the dog was bought, the books were bought,* whereas in BP, the participle have inflected forms: *a casa foi comprada, o chachorro foi comprado, os livros foram comprados.* Additionally, the agent noun phrase is introduced by the preposition *por* in BP and the preposition *by* in English, known also as a *by*-phrase. In BP, the preposition *por* forms contractions with the definite articles *o, a, os, as* and becomes *pelo, pela, pelos, pelas*. In English, this contraction does not happen. The examples below demonstrate these grammatical differences between the passive structure in BP and English.

9) ***A*** *casa* ***foi*** *comprad**a** pel**o** homem (***The** house **was** bought by the man.*)*

10) ***Os*** *livros* ***foram*** *comprad**os** pel**as** meninas. (***The** books **were** bought by the girls.*)*

Having reviewed the types of passives as well as differences in the passive structure between BP and English, it is important to provide information about the pilot study, whose major aim was to test the instruments and procedures. Therefore, the next section describes the participants, procedures of the pilot study as well as reports its preliminary results. Additionally, some changes for the stimuli as well as the procedures are indicated Importantly, these changes were acknowledged to fulfill the objectives of this doctoral investigation.

4.6 PILOT STUDY

In the pilot study conducted in 2014, I made a first attempt at investigating the effects of syntactic priming in children in order to verify whether this population was susceptible to these effects as well as to probe the experimental design. The questions that guided the pilot study were:

1. Do the experimental task and procedures used to assess syntactic priming seem to be adequate for children? Does the experiment implementation demonstrate feasibility in terms of time, equipment, procedures?

2. Do reading times of children show syntactic priming effects for passive sentences? In other words, are children susceptible to syntactic priming?

As mentioned above, the primary objective of the pilot study was to assess the effectiveness of the experimental task and procedures. Therefore, only typically developing school-age children were selected to participate in the pilot study. The next subsection describes these participants and the settings used to collect the data (4.5.1). The tasks and procedures adopted for data collection are presented in subsection 4.5.2. Finally, the preliminary results and the limitations and contributions for further studies are discussed in subsection 4.5.3.

4.6.1 Participants and setting

The group of participants recruited for the pilot study consisted of five female and five male students with ages ranging from 11 to 12 years (M_{age} =11.3 years, SD=0.99). The participants had no history of diagnosed reading or language problems and attended the same elementary public school in Florianópolis, Brazil, where the data were collected. All of them were right handed, with normal or corrected to normal vision.

4.6.2 Tasks and procedures

Prior to the pilot study, school teachers were consulted in order to give feedback about participants' reading abilities. Some of the participants were considered to be competent readers and some of them to be slow readers by the teachers. Before starting the experimental task, participants were briefly interviewed about their age, reading preferences, and reading frequency. Then, they read silently a text for comprehension that they had to retell and answered some comprehension questions. Participants also performed a reading task, in which they had to read aloud as fast and accurate as possible. Both reading tasks were assigned as appropriate for the 5th grade based on Saraiva, Moojen and Munarski (2009).[29]

The experimental task consisted of a list of short sentences in the past tense and these sentences were created with the help of the database of word frequency for preschool and first grades in Brazil developed and

[29] It is a collection of texts in Brazilian Portuguese used for reading assessment by language and speech therapists, and psychopedagogists. A more detailed description of this collection is presented in Chapter V, because the text from this collection was also used in Study I.

published by Pinheiro (1996).[30] All sentences were assigned into three blocking conditions: passive voice (with transitive verbs), active voice (with transitive verbs), and actives voice (with intransitive verbs). In total, there were 187 sentences (100 passives and 87 actives). The sentences were organized in mini-blocks: five passives (total of 20 mini-blocks) and 3 to 6 actives (total of 20 mini-blocks). For each mini-block, there was a yes-no comprehension question, where the answer *yes* was equally often as the answer *no* (50/50). Participants pressed a green button for *yes* answers and a red one for *no* answers. An example of an experimental mini-block of passives is given below:

O nome foi dado pela igreja. (The name was given by the church.)
A casa foi dada pelo velho. (The house was given by the old man.)
O anel foi dado pela rainha. (The ring was given by the queen.)
A flor foi dada pelo mágico. (The flower was given by the magician.)
O laço foi dado pela mamãe. (The bow was given by the mother.)
Question: *O laço foi dado pela avó?* (Was the bow given by the grandmother?)

Taking into account the length of the experimental task, a decision was taken to divide it in two sessions with a 5 minutes break in-between. The number of mini-blocks was equally divided between the sessions. The presentation of mini-blocks was counterbalanced by across conditions. Each session started with a mini-block of actives followed by a mini-block of passives, and subsequent mini-blocks of passives were always interleaved with a mini-block of actives. After each mini-block there was a fixation cross ("+") in the center of the screen, indicating a pause for 3 seconds.

Participants performed the experimental task on a laptop computer with a 15-inch screen with a resolution of 1366×768 pixels. The monitor was positioned at a distance between 50 and 60 cm of the participant's eyes, appropriate to their height. The experimental task was run on E-Prime 2.0 Professional Version that enabled the acquisition of accurate data with millisecond precision timing. The E-prime software measured reading times (time between the onset of the stimulus and the touch on the key) in milliseconds as well as response times and answers for comprehension questions. In a word-by-word, center non-cumulative

[30] There is also a database of Brazilian Portuguese word frequency developed by the Interinstitutional Center for Research and Development in Computational Linguistics (NILC/ USP); however, it was decided to choose the database of Pinheiro (1996) due to the young population under investigation. A more detailed description of this database is presented in Chapter V.

self-paced reading presentation, participants controlled the rate of presentation of each word of a sentence by pressing the space bar (only one word at a time) and could not go back to the previous word and read it again.

4.6.3 Results, limitations and contributions

First, the data for the reading comprehension task were analyzed. Participants varied a lot based on the number of words read per minute. The data revealed the slowest reader with 21 words per minute, and the fastest readers demonstrated a reading speed at about 100 words per minute. Nevertheless, participants were not divided into groups of slow (poor) and fast (good) readers. These results were treated as a continuum with no threshold. For a further selection of participants, the reading level would need to be considered, especially when selecting participants for the control group.

The output of the experimental task consisted of reading times (RTs) for each word and responses to comprehension questions and their respective RTs. As expected, the slowest readers demonstrated more difficulties in answering comprehension questions (about 50%-60% of hits). The average percentage of correctly answered questions was 85%-90%. This output was very important as comprehension questions were used in order to control participants' attention. In the pilot study, participants with low percentage of correct responses to comprehension questions were not ruled out, but for the further data analysis this issue should be considered in order to detect outliers.

When exploring the data for passive sentences, two mini-blocks had to be discarded as there was a problem with RTs (not saved). Fortunately, this problem did not affect the rest of the data. Therefore, a new analysis was run on 18 passive mini-blocks (total of 90 sentences). The total time of each sentence, the time of the critical region (words 3, 4, and 5) and the time for the main verb (word4) were analyzed.[31] The data for the whole sentence did not have significant priming effects as RTs between sentence 1 and sentence 2 slightly decreased, and then increased for sentence 3. Comparing the RTs of sentence 2 and sentence 4, there was a decrease of about 3 seconds, but RTs in sentence 5 increased again. When inspecting the RTs for the critical region, there was a decrease in RTs between sentence 1 and sentence 2, but there was

[31] The critical region is the region of interest in passive sentences that comprises word 3 (a past form of the auxiliary verb *to be*), word 4 (past participle) and word 5 (preposition *by*).

no significant change in RTs between other sentences. Further analysis was conducted on RTs of each word of the critical region, which revealed an interesting tendency. The RTs for word 3 showed no priming effects. As regards word 4 (the main verb), there was a big decrease in RTs between sentence 1 and sentence 2, though not significant, followed by a slight increase in sentence 3. In the RTs for word 5, no significant decrease was identified.

Taking into consideration the results of the pilot study, I concluded that there was a general tendency in RT decrease for the whole sentence, the critical region and the main verb across sentences. However, RTs decrease was not statistically significant as there was only a slight difference in mean RTs between sentences. Several limitations might explain these results.

One of the limitations is the small number of participants. As this was the pilot study, the main objective was to test the experimental task, and the procedures. Thus, the selection of participants was random. In addition, conditions for data collection were not very adequate due to some intervening factors like outside noise, poor light, and heat. I believe this could have affected participant's performance.

The most important contribution of the pilot study was about the validity of experimental sentences. All sentences were evaluated by only one teacher and some children commented on some sentences that they had not understood. Therefore, it was decided that it would be important to receive an additional feedback on stimuli from more than one evaluator and not only teachers, but also children of the same age. Moreover, participants complained about the length of the task, which was too tiring for them. This complaint was quite understandable as children are not as patient as adults are and cannot keep attention for a long time. Thus, for further data collection, the experimental task consisted of more lists with fewer sentences (about 20 sentences each) with a small break in-between them. In addition to this, a pause with no fixed time was included after each mini-block. The reason for this inclusion is to give an additional opportunity for participants to stop and rest. During the pilot study, children demonstrated much anxiety. They wanted to perform their best because for them, this task was a form of evaluation and maybe this emotional state might have affected their performance. Thus, it was decided that, for future data collection, it would be necessary to be more emphatic about the idea that the experimental task was not an evaluation and that participants would not receive any grade.

To conclude, I should say that this pilot study was a fundamental part of the research process. Despite the fact that the conditions for data collection and the experimental task had their limitations, the facilitation effects of syntactic priming were observed, thus indicating that syntactic priming during comprehension is, indeed, a fruitful avenue for investigation. The limitations discussed above were considered in the collection of data for the studies reported here. Based on the literature reviewed and the results obtained from the pilot study, I embarked upon the investigation of the phenomenon of syntactic priming in dyslexia. Study I and Study II investigated syntactic priming in dyslexic children, both reported in Chapter V and Chapter VI, respectively. In addition, Study III was conducted with dyslexic adults, reported in Chapter VII. Hence, the three studies are discussed in the subsequent three chapters.

CHAPTER V
STUDY I: INVESTIGATING SYNTACTIC PRIMING EFFECTS IN DYSLEXIC CHILDREN

This chapter presents the behavioral results of Study I conducted to explore syntactic processing in dyslexic children, students of public schools in Brazil. The main objective of this investigation was to understand whether this special population is susceptible to syntactic priming effects. More specifically, Study I aimed at verifying the implicit learning account of these effects (Chang, Dell, Bock, & Griffin, 2000).

The chapter is divided in several sections, which provide sufficient details to understand how the experimental task was prepared and employed as well as its results. In the first section of this chapter (5.1), I present the research questions and hypotheses that guided this investigation. In order to pursue the answers to these questions, a multiple embedded research design was adopted as reported in section 5.2. Section 5.3 is devoted to a description of participants' profile. Section 5.4 thoroughly describes the instruments employed for the data collection. The following section (5.5) provides information about the statistical procedures used in the analysis of the quantitative data together with the obtained results. The final section (5.6) discusses the findings reported in the results section in light of the reviewed literature.

5.1 RESEARCH QUESTIONS AND HYPOTHESES

In order to understand better syntactic processing in dyslexia through the syntactic priming paradigm, the central research question of the present dissertation concerns whether dyslexics are susceptible to syntactic priming effects. Taking into consideration the experimental design of Study I, the following secondary research questions were posed:

RQ1: Do reading times of dyslexic children show syntactic priming effects for passive sentences? and for active sentences?

RQ2: Are syntactic priming effects of dyslexics comparable to the ones observed in the control group?

RQ3: Are syntactic priming effects cumulative?

These research questions raised the following hypotheses:

Hypothesis 1: Dyslexics will demonstrate significant priming effects for passive sentences, but not for active sentences.

According to Ferreira and Bock (2006), syntactic priming effects are greater when an infrequent structure like passive voice is primed, the pattern of syntactic priming known as the inverse preference or inverse frequency. In a similar vein, Jaeger and Snider (2007) consider the passive voice strucutre as a more *surprising* structure due to its low frequency. Under this presupposition, greater syntactic priming effects are expected for passive sentences rather than active sentences. Syntactic priming effects for actives are expected to be small or absent due to the ceiling effect of the frequency of this structure (Segaert et al., 2011).

Hypothesis 2: Dyslexics will demonstrate stronger syntactic priming effects than controls.

Since passive sentences are more frequent in written language and dyslexics' difficulties in reading have a strong impact on the amount of linguistic input they receive, it was expected more learning about the passive structure as well as more automatic activation of the representation of this structure, as a consequence of implicit learning (Bock & Griffin, 2000). It was assumed that the control group would also demonstrate syntactic priming effects, but the magnitude of these effects would not be equal to the one of the dyslexic group due to the fact that the control group possesses more experience with linguistic input and such complex structure like the passive voice will not elicit processing difficulties equal to the ones expected from dyslexics.

Hypothesis 3: Dyslexics will demonstrate cumulative syntactic priming effects for passives, but not for actives.

Syntactic priming effects have a cumulative characteristic in support of the implicit learning account. The processing of consecutive passive sentences will be modified due to facilitatory effects of syntactic priming. Having evidence of this modification in terms of decreased reading times, it will be possible to state that it is implicit learning that drives syntactic priming. This cumulative characteristic will be attributed only to the passive voice due to its syntactic complexity and frequency-based specificity.

5.2 RESEARCH DESIGN

The present study was conducted in compliance with Resolution 196/96 of the Brazilian National Council for Health/Ministry of Health. All experimental protocols obtained approval from the Committee for Ethics in Research of the *Hospital Infantil Joana de Gusmão* (Joana de Gusmão Children's Hospital) in Florianópolis, Brazil (No. 956.023) and the procedures for data collection were in accordance with the principles of ethics in research involving human beings 466/12 of the Brazilian National Health Council. The researcher maintained confidentiality of participants' identities and their personal information.

In order to address the research questions and hypotheses of Study I, the following research design was established. Before the application of the experimental task, the present researcher with the help of school principals and teachers handed out written informed consent forms to parents or legal guardians of children (see Appendix A1). Parents or legal guardians, who authorized participation in the study, were asked to fill in a questionnaire with general information (such as age, sex, health and social information) about their children (see Appendix B). They completed a shortened version of the original questionnaire developed by the members of *Projeto ACERTA* (Evaluation of Children in Risk of Learning Disabilities) in Florianopolis that was supervised by Professor Mailce Borges Mota (*UFSC*). It is important to state that *Projeto ACERTA* is a longitudinal project with the primary objective to understand why some children develop learning disorders (dyslexia as well as dyscalculia) and what the early biomarkers of these disorders are. On the day of data collection, participants received a simplified informed consent form and were required to read and sign it, thus expressing their legal and formal agreement (see Appendix A2).

The data collection consisted of two parts. In the first part, participants performed a fluency and reading comprehension task. This part is described in more details in section 5.4.1. The application of this task was crucial for the selection of dyslexic participants since not all recruited dyslexics were able to complete the task due to severe reading problems. Dyslexics who were not able to complete the fluency and reading comprehension task were, nevertheless, invited to the second part of the experiment in order to avoid further feelings of shame and embarrassment over their reading difficulties.

In the second part, after a short break, the selected participants performed the experimental task in front of a 14-inch HP laptop (for details, see section 5.4.2). The experimental task was developed and presented using the E-Prime 2.0 software. The experimental sentences were displayed using a word-by-word, center non-cumulative self-paced reading presentation, i.e., participants controlled the rate of presentation of each segment by pressing the space bar. The use of this type of presentation seems to be most appropriate to accomplish the objectives of the research because it provides accurate information about on-line sentence processing. In this type of stimulus presentation, participants read only one word at a time on the center of the screen. They cannot go back to the previous word and read it again (Marinis, 2010). Moreover, as the stimulus presentation is not cumulative, participants do not have an idea about the length of each sentence, i.e., no predictions and/or expectations regarding upcoming words can be made.

Prior to the experimental task, the researcher read aloud the instructions presented on the monitor of the laptop together with the participant, who also had the opportunity to clarify doubts about the procedures. Afterwards, the participant had a short practice session. If necessary, the participant could repeat the practice session. Once the participant felt confident enough to perform the task, s/he could start the task. Due to the amount of experimental stimuli, the task was split into ten block-lists with four mini-blocks of sentences each. After each list, there was a break of about 2 minutes. In the end of the experimental task, no feedback about participants' performance was provided.

5.3 PARTICIPANTS

In a voluntary condition, thirty-three children with adequate reading level for their age (the control group) and 27 children and adolescents with developmental dyslexia (the dyslexic group) participated in the present study. All participants were monolingual, native speakers of Brazilian Portuguese, and students of public schools in *Grande Florianópolis* region, Brazil. Dyslexic participants had official diagnosises of dyslexia issued either by multidisciplinary teams of specialists or individual specialists such as educational psychologist and pediatric neurologist. No additional assessments were conducted in order to attest their diagnosis. The control group had no history of language/reading or neurological disorders. All the participants had normal or corrected to normal vision. In addition, all participants of the control group were enrolled in the schools that were part of *Projeto ACERTA*.

Based on data pre-processing, which are described in section 5.5.1, the final sample of participants consisted of 20 dyslexic children and adolescents from 10 to 16 years old (M=12.8 years, SD=1.36) and 25 controls from 10 to 11 years (M=10.5 years, SD=0.5). The groups were thus not closely matched for chronological age. The following two constraints limited the recruitment of dyslexic participants: the need for a formal diagnosis of dyslexia and a reasonable reading fluency. In Brazil, children with learning difficulties are submitted to some form of diagnostic assessment only after the 3rd grade of primary school, between 8 and 10 years old (Rotta, Filho, & Bridi, 2015). However, in reality children in Brazil often receive a diagnosis even later. The majority of dyslexics who participated in this study were diagnosed at the age of 10-

11. It is important to emphasize that only after the formal diagnosis, children in Brazil have rights to receive support at schools and additional intervention. Furthermore, not all children with a diagnosis of dyslexia could be selected to participate in this study due to their severe difficulties in decoding single words. Importantly, an additional statistical test was carried out for the dyslexic group to determine whether there was a significant interaction between age and the effect of sentence repetition, and the results showed no significance (p>.667). This suggest that the age of the dyslexic group thus does not determine the observed priming effects.

Although the experimental and control groups were not closely matched for chronological age, the number of male participants was the same: 13 boys and 7 girls in the dyslexic group and 13 boys and 12 girls in the control group.[32] Table 5.1 summarizes the data about participants of each group. Dyslexic participants were numbered from 2 to 28, and control participants were numbered from 30 to 61 and also participant number 1 (the number attributed by mistake).

Table 5.1
General information about the participants (Study I)

Group	Participant	Age	Sex	Reading (wpm)
Dyslexic participants	2	11	m	86
	3	13	f	31
	4	12	m	62
	5	12	f	55
	8	16	m	36
	9	11	m	21
	11	15	m	28
	12	12	m	81
	13	12	f	92
	14	14	m	72
	15	14	f	123
	16	12	f	40
	17	12	f	47

[32] Traditionally, dyslexia was thought to be more common in boys than in girls; however, recent data provide evidence of similar number of dyslexic boys and girls (Nicolson & Fawcett, 2008; Shaywitz et al., 2001).

	20	14	m	33
	23	14	f	48
	24	12	m	60
	25	12	m	23
	26	12	m	40
	27	14	m	170
	28	12	m	67
Control participants	1	11	f	105
	30	11	f	141
	32	11	m	114
	33	10	m	100
	34	11	m	145
	37	10	f	98
	38	10	m	93
	40	10	f	128
	42	10	m	115
	43	11	f	132
	44	10	f	114
	45	11	f	118
	47	10	m	141
	48	11	m	83
	49	10	m	117
	51	10	f	99
	52	10	f	127
	54	11	f	164
	55	10	m	105
	56	10	f	100
	57	11	f	111
	58	11	m	95
	59	10	m	105
	60	11	m	123
	61	11	m	126

Note. m=male; f=female; wpm=word read per minute.

5.4 INSTRUMENTS

The present section is divided into two parts. In the first part, the task that was used to assess participants' fluency and reading comprehension is described in subsection 5.4.1. The primary purpose of including a fluency and reading comprehension assessment was to control for the recruitment of dyslexic participants. Because it showed that some dyslexic children were not able to decode simple and frequent words, this task helped to select dyslexic participants appropriate for experimental testing. The secondary purpose was to estimate reading age of dyslexic as well as control participants and verify whether their reading age corresponded to their chronological age. The second part of this section (5.4.2) is dedicated to the experimental task with the syntactic priming paradigm. The two instruments are described below.

5.4.1 The fluency and reading comprehension task

The fluency and reading comprehension task was taken from the collection of texts by Saraiva, Moojen and Munarsk (2006). This collection of texts is used by educational psychologists and speech therapists in order to assess fluency and reading comprehension of children with learning and reading difficulties across different school years. The collection consists of simple expository texts, with different text structures (description, problem/solution, cause/effect, comparison, sequence). The length and complexity of texts vary according to specific group ages. Before reading the text, children see an illustration related to the topic of the text, which helps to trigger prior knowledge of the topic. With this task and the help of guiding questions, professionals can measure speed of silent and oral reading (number of words read per minute - wpm). Reading comprehension is measured with the help of guiding questions elaborated for each text.

Considering the designated population (10-12 years old), the fluency and reading comprehension task selected was the one appropriate for the 5th grade. Participants read the text named *Os Lobos* (in English *The wolves*), which contained 246 words (see Appendix D2). Following the instructions given by Saraiva and colleagues (2006), participants were first exposed to the photo of a wolf in black and white and were asked to tell what they knew about this animal (see Appendix D1). Then, they received the text and were asked to read it silently. Afterwards, participants were asked to read the text aloud, as fast and accurate as possible. Their reading was recorded with the use of a voice recording application installed on the cell phone in order to verify the total time of reading. The number of words read per minute was calculated using the formula (246x60sec)/time taken in seconds = number of words read per minute. Then, the experimenter took back the text and asked the participant to retell what s/he remembered from the text and what new information s/he had learnt from it. As participants did not possess the text, it was possible to see how well they could recover the information read and organize it to make up a story. If participants missed some important information, the experimenter made guiding questions. The text was accompanied by ten guiding questions in order to help participant recover main ideas (see Appendix D2). Comprehension was not assessed by means of the number of correctly responded questions because these questions were only used when participants did not remember some information.

5.4.2 The experimental task

An experimental task based on the active-passive sentence alternation with an unrelated active voice structure (e.g., *The girl bought the bag* with the Agent-Verb-Patient structure) and passive voice structure (e.g., *The bag was bought by the girl* with Patient-Auxiliary verb-Main verb-by-Agent structure) was designed for the specific purposes of the present study. The advantage of using these alternations is that these sentences are relatively short, thus avoiding memory load, and also express the same semantic idea with some changes in the syntactic structure (Cantiani et al., 2013).

Given that the magnitude of syntactic priming effects is higher for complex and infrequent sentence structures, syntactic priming effects for passives were of great interest, first and foremost, and actives were used as fillers. In addition to active sentences with transitive verbs, active sentences with intransitive verbs served as filler items (e.g., *The student slept few hours* with the Agent-Verb-Complement structure). Taking into consideration that syntactic priming effects in comprehension are subtle and observed more often with the repetition of the content word, the main verb between primes and targets was repeated (Tooley & Traxler, 2010). Thus, primes and targets shared both structural and lexical overlap at the verb in the experimental task. In order to restrict lexical repetition in sentences only to the verb, other content words were not repeated within a mini-block.

Overall, the experimental task contained 200 sentences (see Appendix E1). Half of these sentences were passives that were investigated for priming effects. The other half contained filler items: 50 active sentences with transitive verbs and 50 active sentences with intransitive verbs. The passive sentences were organized in mini-blocks of five sentences, whereas active sentences were organized in mini-blocks varying from 3 to 7 sentences. The presentation of mini-blocks of passives was intermixed with the presentation of filler mini-blocks. In order to guarantee participants' attention and compliance, each mini-block contained a comprehension question. Half of comprehension questions had the answer *yes* and the other half corresponded to the answer *no*.

Considering the total amount of experimental stimuli, i.e., 200 sentences and 40 comprehension questions, the experimental task was divided into ten block-lists, each with approximately 20 sentences (two mini-blocks of passives and two mini-blocks of fillers) and four comprehension questions. In addition to the obligatory short break of about two mins after each block-list, a pause symbol was introduced after every mini-block so that participants decided whether they needed to pause and rest or proceed with the task.

The sentences were constructed with words taken from the database developed and published by Pinheiro (1996). This is a database of Brazilian Portuguese word frequency for preschool and first grades, which allows the selection of words according to frequency (high, medium and low) and to different academic levels (preschool, 1st, 2nd, 3rd and 4th grades). Semantic categories of these words are people, animals, plants, food, household items, toys, furniture, body parts, clothing and transportation.

An example of a block of sentences in passive voice is presented next (translation from Portuguese):

O jornal foi lido pela babá. (The paper was read by the nanny.)
A página foi lida pelo moço. (The page was read by the young man.)
O título foi lido pelo vovô. (The title was read by grandfather.)
O cartaz foi lido pelo povo. (The poster was read by the crowd).
A sílaba foi lida pela irmã. (The syllable was read by the sister.)
Question: *A sílaba foi lida pela professora*? (Was the syllable read by the teacher?)

The experimental sentences were carefully created considering the word frequency effect. According to Pinheiro (1996), high frequency words have an advantage in time processing and reading accuracy. However, it was not possible to use only high-frequency words in all sentences due to the scarce variability in the database. The majority of content words had high and medium frequencies based on the filters of the database. In addition to word frequency, word length was taken into consideration in the selection of words. Therefore, words with more than ten letters were discarded.

The sentences created for the syntactic priming task were submitted to a test for their acceptability, grammaticality, naturalness, comprehensibility, and appropriateness. First, I showed the original version of sentences to a teacher with more than 25 years of experience in literacy teaching in primary school, part of *Projeto ACERTA*. Based on her feedback, I revised the original version of each sentence and tested the new version with 20 literacy teachers from three primary schools of *Projeto ACERTA*. Each teacher received a printed version of the sentences with instructions for assessment (see Appendix C1). Sentences were assessed on a 5-point Likert scale, from not at all acceptable (score value =1) to completely acceptable (score value=5). Sentences with a mean score of 4 were selected and used in the pilot study.

The results of the pilot study were presented in the PhD proposal and discussed with the members of the PhD qualifying exam. During the discussion about the sentence acceptability test, it was decided to test sentences with children, students of primary schools, who were the target population of the study. Taking into account this population, it was assumed that they would have difficulty with a 5-point Likert scale. Therefore, a 3-point scale was developed using emoticons, i.e., a happy, neutral and sad smiley (see Appendix C2). As the list of sentences were quite long, a math activity was included in order to avoid monotony and boredom. In total, experimental sentences were revised and evaluated by 56 students aged 10-12 years.

The presentation of experimental sentences was implemented in a center non-cumulative self-paced reading paradigm. First, a fixation cross appeared in the center of the screen for 1000ms before every sentence. After this fixed interval, the first word of a sentence replaced the fixation cross. The following words of a sentence appeared on the screen after pressing the space bar, thus substituting the previous one (see Figure 5.1). Reading time (RT) for each word was recorded, i.e., the time between the word presentation and the space bar press. The participants had to answer a sporadic yes-no comprehension question regarding the previously read sentence as quickly and accurately as possible. To answer the question, the participants pressed a green button for *yes* (the *Q* key) or a red button for *no* (the *P* key). The participants did not receive any feedback on their performance by the end of the experiment.

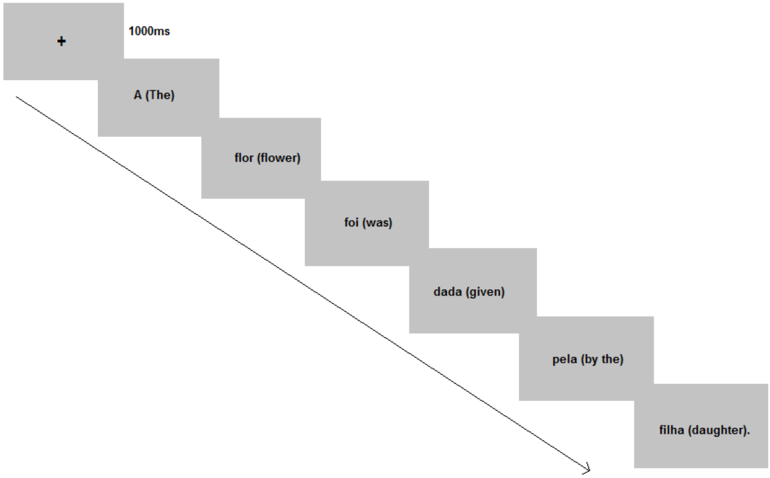

Figure 5.1. Experimental design of a passive sentence presentation (Study I).

Experimental stimuli were presented as a dark blue text on a light grey background in the center of the screen: instructions written in Arial, bold, 22, sentences in Arial, bold, 24, and questions in Arial, bold, 24. Reading times (RT) for each word were recorded, i.e., the time between the word presentation and the space bar press, and these behavioral data were used for the statistical analysis. This syntactic priming during comprehension task, as designed for the purposes of the present study, was also adopted by Kramer (2017) in her study on syntactic priming effects on good and poor readers.

5.5 RESULTS

The present section reports the results of the statistical analyses conducted to address the research questions of Study I. Taking into account the type of data generated by the experimental task, i.e., reading times, the raw data underwent some preprocessing, which is described in section 5.5.1. Based on the preprocessing step some outliers were identified and excluded. The results reported for Study I are based on the final sample without these outliers. With the help of background questionnaires and reading task, it was possible to visualize the profile of both the experimental and control group, which is described in section 5.5.2. Finally, in section 5.5.3, the statistical analyses of the obtained data are presented. The results are reported for the participants' performance on comprehension questions as well as processing passive and active sentences.

5.5.1 Data pre-processing

For data pre-processing, two dependent variables (accuracy on comprehension questions and reading times) were taken into consideration. First, the data were checked for the overall number of correctly answered comprehension questions for each participant. These data were used as indicators of the participants paying attention to the experimental task. The criterion for removing outliers based on accuracy was 1 standard deviation away from the mean number of correct responses for each group. As expected, the dyslexic group made more mistakes on the comprehension questions than the control group (dyslexics M=9, SD=7; controls M=2, SD=2). The dyslexics who answered correctly less than 25 out of 40 questions were considered outliers. For the control group, participants who scored below 36 questions were excluded.

For all reading times, first, all impossible values (under 150ms) for each word were removed as these might be due to some accidental responding. Then, the means and standard deviations for each word of a sentence were calculated and as all values beyond the Mean±1,5SD range were considered as outliers and removed. The means and standard deviations were calculated for dyslexics and controls separately. In general, only the first word of the sentence (the article), which is not the focus of this investigation, had the highest number of missing data (13,4%). The percentage of missing data for other words ranged from 4 to 11%, which is considered normal (Ratcliff, 1993). Overall, the screening procedure based on accuracy and reading times eliminated seven participants from the dyslexic group and eight participants from the control group. As a result, the data of 20 dyslexics and 25 controls were investigated further.

5.5.2 Participants' profile

As mentioned above, the questionnaire applied to gather information about the participant was essential to make inferences about the profile of each group. Responses to the questions regarding the socioeconomic, educational, and health aspects were analyzed and the results are described below. Since the respondent, usually one of the parents of the participant, filled in the questionnaire at home, some questions were left unanswered, thus generating some missing data.

The analyses of the responses showed that the first aspect that is closely related to the literacy success of the participant is the socioeconomic status of the student's family. The average income of the family was established in the number of the national minimum salary and the respondents informed the number of salaries received per month. At the time of data collection, the national minimum salary was R$788.00, which was approximately equivalent to USD245. In the dyslexic group, 5% of the families reported counting on one minimum salary, 40% - two minimum salaries, 20% - three minimum salaries, 5% - seven minimum salaries, and 5% with eight minimum salaries. Twenty-five percent of respondents did not answer this question. In regard to the control group, 12% of the families lived on one minimum salary, 20% - two minimum salaries, 16% - three minimum salaries, 12% - four minimum salaries, 16% - five minimum salaries, 4% - six minimum salaries, and 8% on eight minimum salaries. Twelve percent of respondents did not answer this question. Comparing these data, the control group seemed to be economically more fortunate.

As a family income is related to educational level, the questionnaire inquired about respondents' highest level of education. In the dyslexic group, 30% of the respondents reported having incomplete primary educational level, 20% complete primary level, 5% had incomplete high school level, 15% had complete high school, and 5% complete higher education. Twenty-five percent of respondents did not answer this question. The respondents of the control group had the following educational level: 12%, had incomplete primary educational level; 8% had complete primary level; 8% incomplete high school level; 20% complete high school; 12% incomplete higher education, and 28%, complete higher education. Again, the control group had a more favorable educational level in the family.

Some health aspects about the participants and their families were assessed. First, the family history of psychiatric and learning (developmental) disorders revealed that in both groups there were some cases of genetic disorders in the family (a close relative like mother or father or a more distant relative, like aunts and uncles). For the dyslexic group, 45% of the respondents confirmed family cases of disorders. Thirty-five percent of respondents did not answer this question. For the control group, only 20% of the respondents reported family cases of disorders. Twelve percent of respondents did not answer this question.

Therefore, the dyslexic group had greater genetic susceptibility to certain disorders, as there were twice as many cases of genetic disorders.

The respondents of the dyslexic group also reported that 25% of participants use some prescribed medication. Twenty percent of respondents did not answer this question. The ones that informed the type of medications listed medications for health problems like allergies or diabetes. Only one dyslexic consumed Ritalin as prescribed to treat this specific learning disorder. Twelve percent of the control group used some kind of medication. Twelve percent of respondents did not answer this question. The health problem that also has the potential to affect academic and reading development is a vision problem. Twenty percent of dyslexics had some vision problem and 15% did not wear glasses as prescribed due to no specified reasons. As regards the control group, 48% of participants had vision problems and only 4% reported that they did not wear glasses.

In addition, it was important to know whether the participants practiced some kind of sport. In the dyslexic group, 55% were involved in some sporting activities. Fifteen percent of respondents did not answer this question for the dyslexic group. As regards the control group, 52% were in sports training. Twelve percent of respondents did not answer this question for the control group.

For the dyslexic group, the questionnaire had an additional question about the age when the participant had been diagnosed with dyslexia. A majority of dyslexics received the diagnoses between 8 and 11 years old (20% at the age of 8; 20% at the age of 10, and 25% at the age of 11). Five percent of dyslexics were diagnosed at the age of 12, and 5% at the age of 14. Some, but not all dyslexics repeated the 3^{rd} grade at school (50%). Twenty percent of respondents did not answer this question.

Regarding the performance on the reading comprehension task, the results were the following. As expected, the dyslexic group was much slower than the control group. The mean number of word read per minute (wpm) was 60.75 (*SD*=36.70) for dyslexics and the control group performed nearly twice faster (*M*=115.96, *SD*=18.99). Moreover, as can be seen, the value of standard deviation is also twice bigger for dyslexics, which means that the variation of the data values was quite spread out. Indeed, looking at the minimum and maximum values of the dyslexic group, the slowest dyslexic participant had a score of 21 wpm and the fastest one, a score of 170 wpm. As for the control group, the slowest participant read 83 wpm and the fastest one read 164 wpm. The difference in the number of words read per minute between the groups was significant t(27.03) = -6.11, p<.001), and it represented a large-sized effect *r*=0.76.

5.5.3 Analyses of the behavioral data

The experimental task output consisted of the accuracy data regarding the comprehension questions and the data for reading each word of a sentence. First, the accuracy data for each condition are provided. Then, statistical analyses of processing passive and active sentences are reported.

5.5.3.1 Comprehension question accuracy

Examining the percentage of correctly answered comprehension questions, the dyslexic group was significantly less accurate than the control group in all conditions (actives with transitive verbs: $t(26.08)= -3.56$, $p<.01$; actives with intransitive verbs: $t(20.31)= -2.70$, $p<.05$; passives: $t(21.37)= -4{,}40$, $p<.001$). Figure 5.2 reports the accuracy percentage on comprehension questions for each group. Comparing accuracy across the conditions, dyslexics made more mistakes in answering questions related to passive sentences than to active sentences with intransitive verbs ($t(19)= -2.22$, p<.05), but this was not significantly different from active sentences with transitive verbs ($t(19)= -1.21$, p>.05). The control group also made more mistakes in answering comprehension questions related to passive sentences than to active sentences with intransitive verbs ($t(24)= -1.21$, p<.05), but their performance was not significantly different in the case of active sentences with transitive verbs ($t(24) = -0.58$, p>.05).

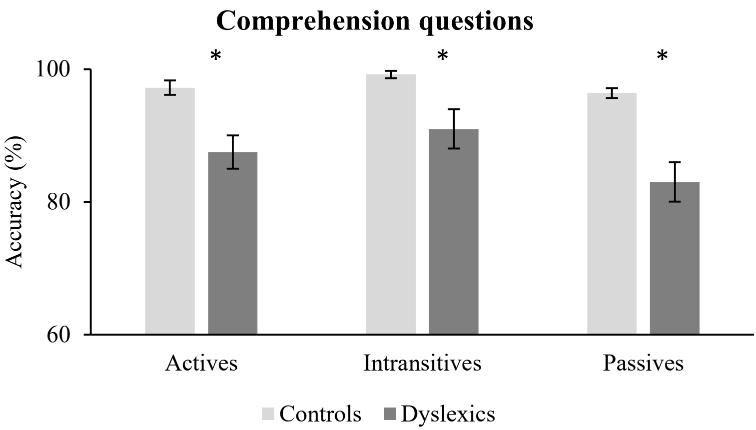

Figure 5.2. Accuracy percentage on comprehension questions (Study I).
Note. Error bars denote one standard error around the mean. An asterisk (*) indicates statistically significant differences between the groups.

5.5.3.2 Analyses of passive sentence processing

Figure 5.3 and Figure 5.4 report mean reading times of each word in a sentence within a mini-block for dyslexics and controls, respectively. When comparing the passive voice structure to the active one (its alternative structure) considering only the syntactic characteristic, the complexity of the passive voice structure is evident due to the auxiliary verb, the participle and the by-preposition. Therefore, these three words were considered as the critical region for further analysis. Following the report of the analyses for the critical region, the analyses for the verb only (word 4) are presented since Figure 5.3 and Figure 5.4 show that the effects may be located primarily at the verb.

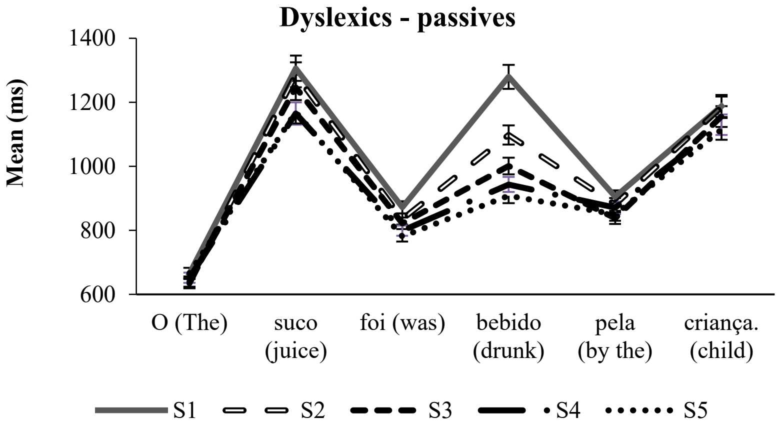

Figure 5.3. Mean reading times for passive sentences in the dyslexic group (Study I).

Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the last, fifth sentence.

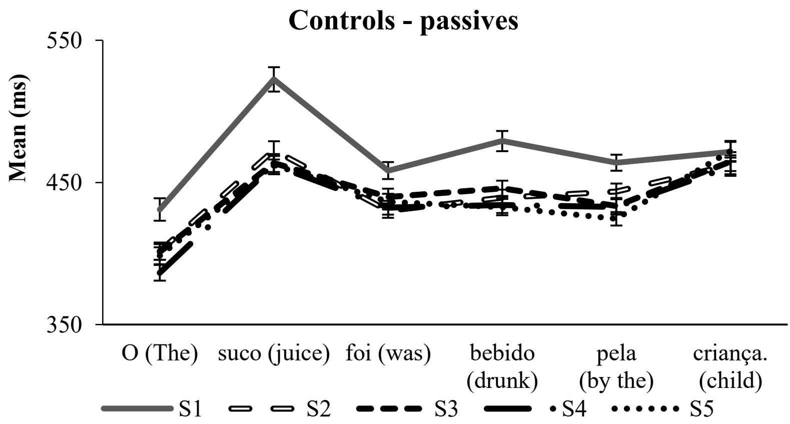

Figure 5.4. Mean reading times for passive sentences in the control group (Study I).

Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the last fifth sentence.

Based on the statistical analyses on reading times (RTs) for the critical region (words 3, 4 and 5), the results of the repeated-measures ANOVA (rANOVA) with a Greenhouse-Geisser correction indicated a significant main effect for sentence repetition ($F(1.80,77.30)=35.12$, $p<.001$) and a group by sentence repetition interaction ($F(1.80,77.30)=12.59$, $p<.001$). The follow-up analysis of the Bonferoni post-hoc test revealed a significant difference in means between sentence 1 repetition and the remaining four repetitions in both groups ($p\leq.01$). In addition, there was also a statistically significant difference in means between sentence 2 and sentences 4 and 5 ($p<.01$) in the dyslexic group. With regard to the control group, there were no further statistically significant mean differences in RTs.

As dyslexics are overall a lot slower in reading than controls, it is difficult to compare the effects of syntactic priming between the groups. Therefore, absolute values were transformed into relative ones and the relative reduction of RTs in percentages, in relation to sentence 1 was calculated (RT difference between S1 and Sx/S1* 100= X%). Figure 5.5 reports these data.

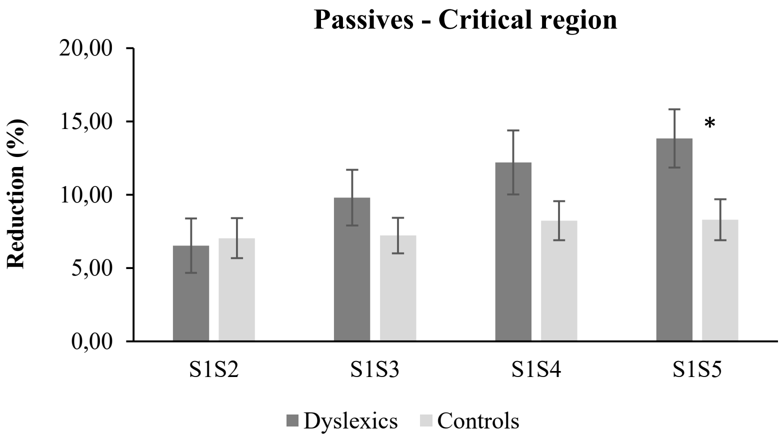

Figure 5.5. Relative reduction for the critical region reading times of passive sentences (Study I).
Note. Error bars denote one standard error around the mean. S1S2 indicates the relative reduction in reading times between sentence 1 and sentence 2. S1S3 refers to the reduction between sentence 1 and sentence 3. S1S4 corresponds to the relative reduction between sentence 1 and sentence 4, and S1S5 informs the overall reduction between sentence 1 and sentence 5. An asterisk (*) indicates statistically significant differences between the groups.

In the dyslexic group, the relative reduction of RT means compared to the first sentence presentation cumulatively increases with each sentence repetition. For instance, the reduction from sentence 1 to sentence 2 is 6.52% and the overall reduction between sentence 1 and sentence 5 is twice as larger (13.83%). In relation to the control group, the reduction from sentence 1 to sentence 2 is similar, 7.03%, but it does not change significantly with more sentence repetitions (only 8.28% between sentence 1 and sentence 5). Therefore, it was concluded that both groups did not differ in the relative reduction between sentences 1 and 2, $t(43)=0.23$, $p>.05$; between sentences 1 and 3, $t(43)= -1.19$, $p>.05$; between sentences 1 and 4, $t(43)= -1.62$, $p>.05$. However, there was a statistically significant difference on the overall reduction, $t(43)= -2.35$, $p<.05$. These results made us conduct further statistical analysis on the repeated verb presented next.

Based on Figure 5.3, dyslexics' priming effects are all about the main verb (word 4), whereas Figure 5.4 shows that controls seem to have similar effects throughout the critical region, i.e., the distribution of the priming effects is more widespread. Therefore, the rANOVA was conducted for word 4. The results of the rANOVA with a Greenhouse-Geisser correction showed a significant main effect for sentence repetition ($F(1.34, 57.76)=42.94$, $p<.001$) and group by sentence repetition interaction ($F(1.34, 57.76)= 26.29$, $p<.001$). The Bonferoni post-hoc test indicated a significant difference in means between sentence 1 and the remaining four sentence repetitions in both groups ($p<.001$). Moreover, there was also a statistically significant difference in means between sentence 2 and sentences 3, 4 and 5 ($p<.01$) and sentences 3 and 5 ($p<.05$) in the dyslexic group. In regard to the control group, there were no further statistically significant mean differences.

The absolute data for word 4 was also transformed into relative data in order to compare syntactic priming effects between the groups (see Figure 5.6).

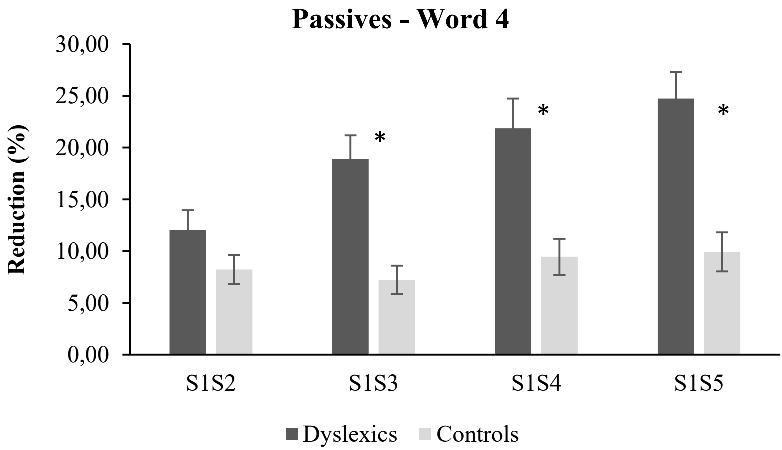

Figure 5.6. Relative reduction for word 4 reading times of passive sentences (Study I).

Note. Error bars denote one standard error around the mean. S1S2 indicates the relative reduction in reading times between sentence 1 and sentence 2. S1S3 refers to the reduction between sentence 1 and sentence 3. S1S4 corresponds to the relative reduction between sentence 1 and sentence 4, and S1S5 informs the overall reduction between sentence 1 and sentence 5. An asterisk (*) indicates statistically significant differences between the groups.

Looking at the relative reduction data in percentage, there was a cumulative decrease in reading for word 4 in the dyslexic group in relation to sentence 1. The reduction in RT means from sentence 1 to sentence 2 is 12.08% and the overall reduction from sentence 1 to sentence 5 is 24.76%. In the control group, the reduction from sentence 1 to sentence 2 is 8.35% and the overall reduction is 9.94%. Comparing these data, the groups did not differ in the relative reduction between sentences 1 and 2, $t(43)= -1.68$, $p>.05$. However, the relative reduction was significantly different between sentences 1 and 3, $t(31.79)= -4.41$, $p<.001$. Moreover, there was a statistically significant difference in the reduction between sentences 1 and 4, $t(43)= 0.23$, $p<.001$ and the overall reduction (between sentences 1 and 5), $t(43)=0.41$, $p<.001$.

To summarize, the above presented results for passives revealed that priming effects in the dyslexic group reflected facilitated on-line processing to a greater extent than in the control group. In the critical region, priming effects were more pronounced across sentence repetitions in the dyslexic group than in the control group. In both groups, priming effects were significant between sentence 1 repetition and other four sentence repetitions ($p \leq .01$). However, only the dyslexic group demonstrated significant effects across other sentence repetitions (sentence 2 and sentences 4 and 5, $p < .01$). Examining the data for the repeated verb, the dyslexic group showed significant priming effects between sentences 1 and 2 ($p < .001$) and sentences 2 and 3 ($p < .05$), whereas the control group only had significat priming effects between sentences 1 and 2 ($p < .001$). The comparison of priming effects in word 4 identified significant difference between sentence 1 and sentences 3, 4 and 5. These results suggest that the dyslexic group demonstrated larger priming effects than the control group and that these effects were more strongly associated with the main verb (past participle) repetition.

5.5.3.3 Analyses of active sentence processing

In the previous section, syntactic priming effects were reported for passive sentences where the syntactic structure as well as the verb were repeated within mini-blocks. To examine the extent to which these effects are driven by lexical repetition rather than syntactic structure repetition, the control analyses on active sentences were carried out. Syntactic priming effects for actives are expected to be small or non-existent and the effects are usually observed for passives only (Ferreira & Bock, 2006). If the effects for passives are solely due to lexical repetition, then equally large effects for actives should be observed, since in actives the verb was also repeated within mini-blocks. However, if priming effects differ for actives and passives, then it will be possible to claim that the observed priming effects for passives are at least in part due to the repetition of the syntactic structure, and not solely due to the repetition of the verb.

The mean reading time per word for each active sentence within mini-blocks was retrieved. Figures 5.7 and 5.8 present these data for dyslexics and controls, respectively. As Figure 5.7 shows, the dyslexic group demonstrated some conceivable priming effects for the main verb (word 3) between sentence 1 and sentence 2, whereas the control group lacked these effects for the verb (Figure 5.8). Therefore, a statistical analysis was conducted only for word 3.

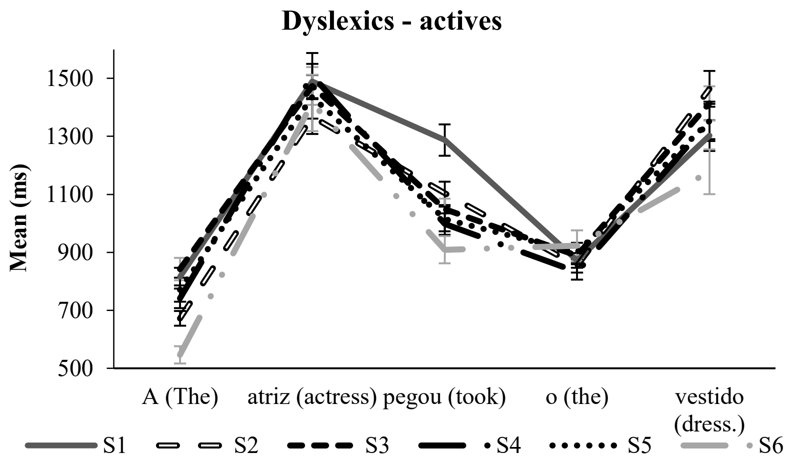

Figure 5.7. Mean reading times for active sentences in the dyslexic group (Study I).

Note. Error bars denote one standard error around the mean.S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the last fifth sentence.

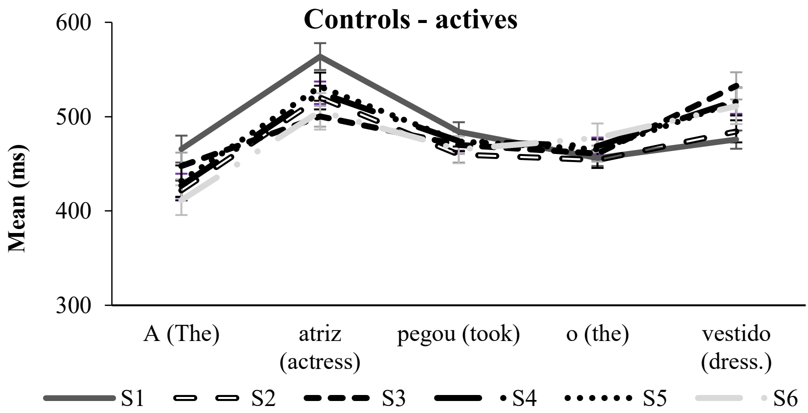

Figure 5.8. Mean reading times for active sentences in the control group (Study I).

Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the last fifth sentence.

The same screening procedures were applied to the data for actives. The results of the repeated-measures ANOVA with a Greenhouse-Geisser correction showed a significant main effect for sentence repetition ($F(1.86, 80.01)=22.38$, $p<.001$) and group by sentence repetition interaction ($F(1.86, 80.01)= 18.90$, $p<.001$). Analyzing the data for each group separately, priming effects were siginificant for the dyslexic group ($F(1.73, 32.96)=17.32$, $p<.001$). The analysis of the Bonferoni post-hoc test revealed a significant difference in means between sentence 1 and the remaining five repetitions in the dyslexic group ($p<.05$). In addition, there was also a statistically significant difference in means between sentences 2 and 4 ($p<.05$), sentences 2 and 6 ($p<.001$), sentences 3 and 6 ($p<.001$), sentences 4 and 6 ($p<.05$). In relation to the control group, syntactic priming effects were not siginificant ($F(5, 120)=2.16$, $p=.063$).

Based on the relative data reported in Figure 5.9, it is possible to see that the overall reduction between sentences 1 and 6 in the dyslexic group is 25.63%, whereas in the control group it is only 4.30%, which is the largest reduction in RT means. These data also corroborate the finding that dyslexics benefit from syntactic repetition more than controls by showing larger priming effects. Comparing these data more closely, some differences in the relative reduction between the two groups were identified. Although there were no significant differences between sentence 1 and sentence 2, $t(43)= -1.16$, $p>.05$, other comparisons revealed significant differences: between sentences 1 and 3, $t(30.03)= -3.38$, $p<.01$; between sentences 1 and 4, $t(24.74)= -4.10$, $p<.001$; between sentences 1 and 5, $t(30.37)= -4.08$, $p<.001$, and the overall difference within the mini-block (between sentences 1 and 6), $t(38.03)=-5.67$, $p<.001$.

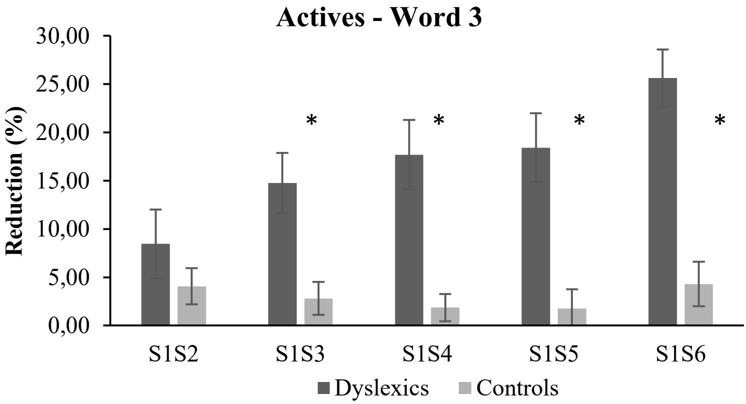

Figure 5.9. Mean reading times for word 3 of active sentences (Study I).

Note. Error bars denote one standard error around the mean. S1S2 indicates the relative reduction in reading times between sentence 1 and sentence 2. S1S3 refers to the reduction between sentence 1 and sentence 3. S1S4 corresponds to the relative reduction between sentence 1 and sentence 4; S1S5 informs the reduction between sentence 1 and sentence 5, and S1S6 – the overall reduction betweens sentence 1 and sentence 6. An asterisk (*) indicates statistically significant differences between the groups.

Based on the analyses for actives, it is possible to conclude that the two groups processed actives in a qualitatively different manner. The dyslexic group showed significant priming effects for the first target sentence ($p<.05$), whereas the control group did not demonstrate significant priming effects ($p>.05$).

Comparing the overall relative reduction of passives to actives, there was a significant difference for the dyslexic group, $t(19)=-2.21$, $p<.05$, where the reduction of response times were bigger for passives. In the same vein, the control group demonstrated stronger priming effects for passives than for actives, $t(24)=-2.65$, $p<.05$. These results were expected as they are in line with the inverse preference account, which states that the magnitude of syntactic priming effects is stronger for the less preferred structure or the structure that is more poorly known, thus being subject to greater learning (Ferreira & Bock, 2006; Pickering & Ferreira, 2008).

5.6 DISCUSSION

The main objective of Study I was to explore how dyslexics process complex sentences and whether they demonstrate difficulties at the syntactic level. It is important to reiterate that by sentence processing, I mean on-line operations that occur when an individual reads sentences in real time. Attesting such difficulties would provide additional support to a syntactic processing deficit in dyslexia as evidenced in previous studies (e.g., Leikin & Assayag-Bouskila, 2004; Rüsseler et al., 2007; Wiseheart et al., 2009). The specific objective of the reported study was to gain a better understanding of syntactic representations in dyslexia through the syntactic priming paradigm.

As presented above, Study I consisted of three main steps. The first step was the recruitment of participants. During this step, it was possible to verify the profile of participants. Although genetic factors are strongly related to heritability of the developmental dyslexia up to 80% (Schumacher, Hoffmann, Schmäl, Schulte-Körne, & Nöthen, 2007), parental socioeconomic status (SES) may have a great impact on very early development of an individual. A substantial body of studies has focused on understanding how a child`s living environment affects the development of literacy skills and has shown that low SES correlates with delayed acquisition of literacy skills (Duncan & Seymour, 2000; Seymour & Evans, 1999).

The analysis of the questionnaire data demonstrated the following characteristics of the population in each group that are worth discussing. The control group was represented by the participants with a higher SES. Having more favorable financial conditions, the control group had more access to resources for their academic and cognitive development. For instance, many participants from the control group were enrolled in private courses of foreign languages or some other extracurricular activities. Research on the impact of extracurricular activities demonstrated positive associations with academic performance (Lerner, Lerner, & Benson, 2011). Moreover, the control group had access to collections of books that were popular among this age group because their parents could buy them. This was especially remarking because when interviewing participants about their reading preferences, a few dyslexic participants replied that they would like to read some books they did not have access to at school library and their parents could not afford to buy.

The construct of SES does not include only material wealth of the family, but also education of parents. Financial conditions are subserved by the occupational status, which in turn is associated to the level of education. The questionnaire data revealed that the parents of the control group had a higher level of education and also occupied higher professional positions in comparison to those of the dyslexic group. According to Davis-Kean (2005), parental educational level is also a significant predictor of children`s academic achievement. Therefore, it may be assumed that the dyslexic group was more disadvantaged in comparison to the control group. Educational level of parents reflects in their beliefs and behaviors that they pass to their children (Davis-Kean, 2005). Specifically, parents` reading habits may influence those of their children. For instance, if parents demonstrate negative or indifferent attitudes toward reading, this may discourage children from reading. In addition, time that parents dedicate to children in order to help with homework is also crucial. In the questionnaire, very few parents reported that they did not help with homework. Therefore, parents` support and motivation towards reading and studying in general plays a fundamental role in the foundation of literacy skills.

Information related to familial health and the health of participants is also worth discussing. In the dyslexic group, parents reported some problems related to learning difficulties or mental disorders in the family, which represent some potential genetic risks. Genetic linkage studies in dyslexic families have provided great consistency for inherited factors responsible for the familial dyslexia (Schumacher et al., 2007). Moreover, the dyslexic group consumed more medication than the control group. As there were generally no information about what type of medication dyslexics consumed and whether the use was continuous, it is hard to deliberate on this issue. In addition, the control group reported more cases of vision problems than the dyslexic group, and children that had glasses prescription did not wear them. Although visual impairments may also have genetic causes, it cannot be denied that today children have much more exposure to digital devices and with their excessive use, their vision may be affected as well. Any vision problems represent potential risks for children’s academic development because most learning materials are presented visually. Therefore, the role of parents is essential in intervening and preventing vision deterioration of their children.

Finally, the issue related to the age when dyslexics were officially diagnosed with dyslexia is of crucial importance to discuss. Only few dyslexics were diagnosed at the age of 8, i.e., after approximately 2 years of exposure to formal literacy activities. Unfortunately, many children are diagnosed with dyslexia late at life when their peers have already succeeded in learning to read and write and this definitely causes more frustration and stress in children with dyslexia. Without any doubt, late diagnosis and lack of support provoke serious problems in the development of reading and writing abilities. Therefore, it is advisable to seek for assessment at the earliest possible time if parents perceive that their children present constant reading and writing difficulties.

In the dyslexic sample, the age when a child was diagnosed with dyslexia was associated with performance on the reading comprehension task. In this task, participants needed to read aloud an expository text and retell information from the text. Dyslexic participants were selected for the experimental task according to their performance. In this task, both comprehension and reading fluency were measured. As for the comprehension task, all tested dyslexics were able to interpret the text they had previously read. Some dyslexics needed few guiding questions in order to recover some specific information from the text. Noteworthy, no miscomprehension of the text was observed. According to Saraiva and colleagues (2007), the recommended reading rates for the 5th grade is from 130 to 140 wpm. As expected, dyslexics were much below this rate. The reading rate of the dyslexic group varied a lot, from 21 wpm to 170 wpm. The average reading rate of dyslexics was below the recommended one for the 3rd grade, i.e., dyslexics had a general delay in reading skills for at least 2 years. When comparing the age when dyslexics received the diagnosis with the corresponding reading rate (wpm), it could be noticed that the earlier children were diagnosed the higher their reading rate was. This evidence emphasizes the importance of early diagnosis and efficient intervention so that reading experience becomes less laborious and time-consuming for dyslexics (Schatschneider & Torgesen, 2004).

The reading task was also administered to the control group. The objective of its administration was to see the reading level of participants without reading difficulties, the so-called good readers, in order to form a more homogeneous sample for the control group. The reading rate of the control group was also below the recommended reading rate for their age. Less than one third of the control group performed according to the recommended reading rate, i.e., 130-140 wpm. The average reading rate of controls corresponded to the 4th grade (110-130 wpm), i.e., a delay of one year in the development of reading skills. Only four participants out of 25 outperformed the recommended reading level for their age, i.e., above 140 wpm. The issue at stake here is that although all participants of the control group studied in one of the best public schools of the region, their reading skills were not adequate to their age, according to the reading task employed. Further investigation is necessary to verify this issue more thoroughly in order to attest this evidence.

Following Frith (1986), language development does not depend only on the biological, cognitive and behavioral conditions. There are other external (environmental) factors, which surround children and influence their development. Factors like familial education, SES, access to formal instruction, exposure to print materials and others play an important role in the academic and cognitive development of the child. Therefore, for the experimental sample as well as the control one poor performance on the reading comprehension task may be associated to some external factors.

In the experimental task, the performance of dyslexic children and adolescents was compared to the performance of non-dyslexic children on a self-paced reading task in order to answer the three research questions posed for Study I (see section 5.2). During the experimental session, participants read short sentences organized in mini-blocks with passive and active sentences. The passive voice is a complex grammatical structure because it deviates from the canonical subject-verb-object word order, thus being a less preferred syntactic alternative in comparison to the active voice. According to Scarborough (1991), difficulties in sentence processing are easier to detect with lengthy and complex sentence structures. Hence, it was expected that dyslexic children would demonstrate more difficulties while processing this syntactic structure rather than the active one as being less preferred and more surprisal (unexpected) (Jaeger & Snider, 2007). This unexpectedness to process infrequent structures like passives would lead to greater expectations in processing the consequent sentence with the same structure, thus supporting more efficient processing. Consequently, stronger priming effects were expected for passives rather than actives.

The parsimonious analyses of these data revealed that dyslexics differed from controls on: (1) being less accurate on comprehension questions; (2) showing slower response times; (3) having stronger syntactic priming effects. The first two findings were predictable due to the special population in the experimental task. By nature, dyslexics are slower in reading than the typically developing population and their inefficient word recognition demands more attentional resources and working memory capacity that are so important for comprehension. Therefore, inefficient word recognition has a strong impact on reading comprehension (Jenkins, Fuchs, van den Broek, Espin, & Deno, 2003; Landi, 2010). Regarding the latter findings with stronger syntactic priming effects in dyslexics, these were hard to envisage because this was the first study that investigated this issue in this special population, to the best of my knowledge. Therefore, the discussion of these findings deserves more attention.

Overall, the magnitude of syntactic priming effects was stronger for dyslexics than controls. These findings answer the second research question (RQ 2) and are in accordance with Hypothesis 2 posed in section 5.1. While processing target passive sentences, it seems that dyslexics benefited more from syntactic priming than controls. Moreover, their priming effects were cumulative where response times decreased significantly for sentences 2 and 3 in comparison to the prior exposed sentence. For controls, syntactic priming effects were significant only for the first target sentence (sentence 2). These findings also provide the answer to the third research question (RQ 3) and are consistent with Hypothesis 3. As regards the alternate structure processing, significant priming effects for actives were observed only for the first target sentence in the dyslexic group, but no priming effects were found for the control group.

Considering the fact that dyslexics had much higher reading times than controls, a direct comparison of dyslexics' data to those of the control group would not be informative about the magnitude of priming effects . Therefore, comparing the relative reduction of response times between the groups per condition, the following conclusions were made. Both groups demonstrated priming effects for the first target sentence in passive voice and they did not significantly differ on the relative reduction of response times. However, in terms of the overall relative reduction across passive sentences within a mini-block, there was a difference with stronger magnitude of syntactic priming effects in the dyslexic group. With regard to the active condition, again the groups did not differ on the relative reduction between the first prime sentence and the next targets. Nevertheless, a difference appeared for the overall reduction where dyslexics showed stronger priming effects than controls.

Although the comparison of passive and active data was not the primary goal of this study, when looking at how participants processed these distinct syntactic structures, it was possible to see that the magnitude of priming effects differed. In particular, the overall magnitude had a significant difference for the dyslexic group with stronger effects for passives. These findings answer the first research question (RQ 1) and are in line with Hypothesis 1. Similarly, controls showed stronger priming effects for passives in comparison to no effects for actives. In accord with these comparative results, evidence for differential processing of passives and actives was found in both groups regardless verb repetition. In other words, verb repetition between sentences within a mini-block was not alone responsible for differential processing of target sentences. The observed differences may therefore reflect the effects of a syntactic structure repetition.

As expected, priming effects were greater for passives than for actives as the first impose higher syntactic processing demand due to the complexity of the structure. Syntactic priming effects for passives were more pronounced in the dyslexic group than in the control one. These findings led us to conclude that this special population had a greater difficulty in processing the passive structure and, thus, benefited more from being primed than the control group. Under this presupposition, dyslexics showed syntactic processing weakness as evidenced by processing the passive structure. However, due to the repeated presentation, they learned this complex structure and indeed, they did so based on the observed facilitation effects. In light of these findings, it is possible to claim that dyslexics do have a syntactic processing deficit, which is also underpinned by previous studies investigating the relation between syntactic processing and dyslexia (Leikin & Assayag-Bouskila, 2004; Rüsseler et al., 2007; Wiseheart et al., 2009).

In a similar vein, syntactic priming effects were more durable for the dyslexic group and these results are consistent with the account of implicit learning as a mechanism driving syntactic priming (Chang et al., 2006; 2000). According to this account, once the syntactic structure is exposed, it is activated and preferences for this particular structure increase. The dyslexic group showed priming effect for the first and second target sentences, i.e., cumulative priming effects. In accord with the implicit learning account, learners make predictions about the upcoming structure based on their preferences and if their predictions are erroneous, for example, when a passive sentence is followed by an active one, some adjustments take place in the system. Prediction and error-based learning are core elements of this account. Long-lived patterns of syntactic priming for dyslexics observed in the studies reported in this dissertation may be explained by unconscious learning of passive syntactic structure.

To conclude, the results of the present study contribute to the area of dyslexia research attesting that dyslexics are susceptible to syntactic priming effects. In addition, these effects are long lasting, thus they turn to be even more beneficial to this special population. According to Ehri (2005), with practice, word reading becomes more automatic, i.e., a learner accesses the meaning and pronunciation of words directly from the memory, they are known by sight by sight, without having to decode letter by letter. This is the most efficient way of reading. In the same vein, the beneficial effects can be attributed to the syntactic structure, when it is frequently repeated. With more exposure to one specific structure, its processing becomes more automatic and fluent because a learner spends less effort in processing this structure. Therefore, in light of the findings of the present study, it can be concluded that dyslexics can overcome difficulties in syntactic processing through the repetition of syntactic structures.

Having reported the results of Study I, the next chapter will report Study II, which is a continuation of Study I. Study II also presents the findings of syntactic priming effects during sentence comprehension in dyslexic children. In addition to the behavioral data, the findings of brain imaging data obtained from these children are discussed next.

CHAPTER VI
STUDY II: INVESTIGATING SYNTACTIC PRIMING EFFECTS IN DYSLEXIC CHILDREN WITH FMRI

The present chapter describes the study in which syntactic priming effects during language comprehension were investigated. With the use of fMRI technique, I looked at neuroanatomical responses of children diagnosed with developmental dyslexia while they processed written active and passive sentences. The experimental task from Study I was adopted for this investigation. The main objective of the present investigation was to identify the brain areas which were activated while participants processed primed active and passive sentences. In addition, the experiment aimed at correlating the participants' neuroanatomical responses with their behavioral responses, i.e., their reading times (RTs), in order to gain a better understanding of sentence processing in dyslexia.

In order to pursue the aforementioned objectives, this study attempted to answer several research questions, which are outlined together with the formulated hypotheses in the first section (6.1) of this chapter. Section 6.2 thoroughly describes the research design. After that, there is a section (6.3) devoted to the description of the participants' profile. Section 6.4 introduces the instruments employed for data collection. The following section (6.5) provides information about the statistical procedures in the analysis of the quantitative data together with the results. In the final section (6.6), there is a discussion of these results.

6.1 RESEARCH QUESTIONS AND HYPOTHESES

The central research question of the present dissertation refers to whether dyslexics are susceptible to syntactic priming effects. Taking into consideration the experimental design of Study II, i.e., the possibility to acquire both behavioral and brain imaging data, the following secondary research questions were posed:

RQ1: Do reading times of dyslexics show syntactic priming effects for passive sentences? and for active sentences?

RQ2: Are syntactic priming effects cumulative?

RQ3: What kind of activation occurs in the left inferior frontal gyrus (LIFG)? Does this activation reflect suppression or enhancement effects?

Drawing on the research questions that guided the study, the following hypotheses were proposed:

Hypothesis 1: Dyslexics will demonstrate significant priming effects for passive sentences, but not for active sentences.

It is expected to observe syntactic priming effects for passives and not for actives due to the fact that the passive voice structure is more demanding to process than the active voice structure. In favor of the implicit learning account, the effects of syntactic priming are greater for passives as being less frequent, i.e., a more surprising structure (Jaeger & Snider, 2007).

Hypothesis 2: Dyslexics will demonstrate cumulative syntactic priming effects for passives, but not for actives.

I expect syntactic priming effects to be cumulative and long lasting as support to the implicit learning account. If I find that the processing of abstract syntactic representations changes over the consecutive exposure to passive sentences (based on a decrease of reading times), then it is possible to claim that implicit learning takes place.

Hypothesis 3: The effects of syntactic priming will be evident in the left inferior frontal gyrus (LIFG) in terms of reduced activation for passives, but not for actives.

As proposed in the MUC model (Hagoort, 2007, 2013), the unification component is responsible for computing syntactic information. Results from numerous neuroimaging studies provide reliable evidence to the role of LIFG in unification operations of language. Neuroimaging studies on priming effects (Henson, 2003; Wiggs & Martin, 1998) show that repetition suppression reflects behavioral priming where implicit and automatic responses to stimuli occur. Therefore, I expect to observe repetition suppression in the blood oxygenation level dependent (BOLD) responses within the LIFG area in line with facilitation in behavioral performance.

6.2 RESEARCH DESIGN

In order to address the research questions and hypotheses of the present study, the following research design was established. Participants' background was elicited by means of a questionnaire developed by *Projeto ACERTA* in Porto Alegre, Brazil. In addition, participants' intelligence was measured. It is important to explain that due to the high costs of using an fMRI equipment, no pilot study was conducted.[33] The invited twelve participants performed the experimental task in the period between March, 30th and July, 20th of 2016. Data collection happened in one encounter at *Instituto do Cerebro (InsCer) do Rio Grande do Sul* of *Pontifícia Universidade Catolica do Rio Grande do Sul (PUCRS)* (the Brain Institute of Rio Grande do Sul of the Pontifical Catholic University of Rio Grande do Sul, Brazil) and lasted for about two hours for each participant. As participants were underage, they were always accompanied by an adult in charge of a child. The collection of data was carried out by the collaborators of *Projeto ACERTA* in Porto Alegre under the supervision of professor Augusto Buchweitz (PUCRS).

Before performing the experimental task inside the scanner, the selected participants diagnosed with dyslexia went through the fMRI simulator (also known as a mock scanner), where they could understand the instructions, train the task, see and feel how the real fMRI worked and get used to the noisy environment. This type of simulator is especially useful for preparing special populations, such as children, thus ensuring successful data acquisition.

Once the participant demonstrated confidence in understanding the instructions as well as performing the task inside the real fMRI scanner, the participant and the accompanying adult were taken to the room adjacent to the scan room. The participant was instructed to remove all metal objects like earrings and necklaces. As the fMRI technique is safe and non-invasive, it does not require any special preparations. For instance, no injections are needed and the participant may eat and drink as usual prior to the scan session.

The fMRI experiment was employed to acquire data on a GE Healthcare 3.0T scanner. The fMRI scanner has 33mT/m gradients, operating with LX v.9.1 software and 8-channel quadrature head coils. First, participants performed the experimental task, which is described below. The stimuli were presented on a screen projected in front of the fMRI scanner. The participant viewed the projected stimuli on a screen through an angled custom-built mirror system. There were two pads connected to the button response system which were used to progress the experimental task. Functional images were acquired over time during different conditions of the task. The experimental session lasted for about forty minutes. After that, there was a short break.

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[33] The behavioral experiment (Study I) served as a pilot study for Study II, which helped to make important changes in the experimental task, so that the fMRI experiment could be successfully implemented.

Afterwards, participants performed the unified protocol for structural evaluations during fifteen minutes when the brain structure was measured. Structural images were acquired in three planes: fluid attenuated inversion recovery axial (FLAIR) axes, T2 echo-planar and T1 volumetric axes. As regards the functional images, the blood oxygen level dependent (BOLD) signals were captured using T2-weighted echo-planar imaging (EPI) with a thickness of 3.5 mm, covering the entire brain, a 90º flip angle, and TR = 2000ms. For the diffusion images, the acquisition parameters were as follows: left-to-right phase orientation, TR = 10s, number of directions = 86 (to maximize the ability to calculate the tractography), b-value = 900s/mm2, 256-mm x256-mm field of view (FOV), and 73 slices, resulting in the resolution of 2-mm x 2-mm x 2-mm voxels. The approved protocol contained structural neuroimaging, neuroimaging of resting state, diffusion-weighted neuroimaging, and neuroimaging of tasks (random order).

6.3 PARTICIPANTS

Participants selected for the present study were children diagnosed with developmental dyslexia who attended the ambulatory of *Projeto ACERTA* at *Instituto do Cerebro (InsCer)* of Rio Grande do Sul, Brazil. Diagnoses of these children were carried out by collaborators of *Projeto ACERTA* in Porto Alegre, Brazil as described in Costa and colleagues (2016). All children were assessed on intelligence using the Wechsler Intelligence Scale for Children – the third edition (WISC-III), and reading and writing abilities with the help of the battery of six tests selected from Salles (2005), Saraiva, Moojen and Munarsk (2006), and Moojen (2009) (see section 6.4). Out of all sample of children tested and diagnosed with dyslexia in the context of *Projeto ACERTA*, twelve children agreed to participate in the fMRI data collection for the present study. There were eight males and four females. At the time of data collection, which lasted for five months (between March and July of 2016), the mean age of participants was 11.42 (*SD*=1.24, ranging from 9 to 13 years old). The intelligence assessment showed that the participants' Intelligence quotient (IQ) ranged from 85 to 144 (*M*=109.33, *SD*=16.92). Although twelve participants took part in the experiment, the fMRI data of only eight were considered for subsequent analysis. The reason for the exclusion of four participants was extreme head motion during the experiment, which affected the quality of the brain images obtained. Therefore, the final sample consisted of five males and three females (*M*=11.38, *SD*=1.30, ranging from 9 to 13 years old). Their IQ varied from 86 to 144 (*M*=112.88, *SD*=18.55). Table 6.1 summarizes the data of these participants.

Table 6.1

General information about the participants (Study II)

Participant	**Age**	**Sex**	**IQ**
1	11	m	115
2	12	m	86
3	13	f	103
4	9	m	144
5	12	f	109
6	10	m	112
7	12	f	128
8	13	m	85
9	11	m	103
10	12	m	94
11	10	m	118
12	12	f	115

Note. m=male; f=female.

There is no control group, thus it was not possible to determine whether the tendency (brain activations and reading times) of the experimental (dyslexic) group is different compared to the brain activations and reading times of the control group. For this reason, Study II is exploratory in nature.

6.4 INSTRUMENTS

First, the present section describes the instruments that were used by *Projeto ACERTA* to identify dyslexic children. To assess children's intelligence, a reduced version of Wechsler Intelligence Scale for Children was used (6.4.1). Children's phonological abilities, including reading and writing, were assessed by the battery of tests described in 6.4.2. The results of two years of *Projeto ACERTA* together with these instruments and procedures are reported by Costa and colleagues (2016). As already said, the participants of the present study were selected from the list of children diagnosed with dyslexia by the *Projeto ACERTA* research group in Porto Alegre, Brazil. The experimental task that these participants performed inside the fMRI scanner is described in 6.4.3.

6.4.1 Wechsler Intelligence Scale for Children – the third edition (WISC-III)

Participants' intelligence was assessed by a reduced version of the Wechsler Intelligence Scale for Children – the third edition (WISC-III). The intelligence test consisted of several subtests. The performance of children in these subtests resulted in three scores: verbal intelligence quotient (VIG), performance intelligence quotient (PIG) and full scale intelligence quotient (FSIG).

The IQ test was applied by an undergraduate student of Psychology, scholarship holder of *Projeto ACERTA*, supervised by a professional psychologist, in a room of the ambulatory at the São Lucas hospital in Porto Alegre, Brazil. The test session lasted for approximately 40 minutes. After completing the IQ test, the data were analyzed and stored in the database of *Projeto ACERTA*.

6.4.2 Reading and writing skills

Participants performed a battery of reading and writing tests at the São Lucas hospital as well. The test session was carried out individually with each participant. Family members that accompanied participants waited for them at the reception in order to avoid any interference. Speech therapists were responsible for the tests' execution and checking. The test session took about 40 minutes and no breaks were necessary between the tests. The tests were rated and included in the database of the project according to the procedures employed by *Projeto ACERTA*, as reported in Costa and colleagues (2016). In addition, each family received a detailed feedback in the participant's performance. A brief description of each test is presented next.

6.4.2.1 Reading skills

Reading skills were assessed by two tests. The test of reading words and pseudowords was selected from Salles (2005). This test assesses accuracy and fluency in decoding isolated words and pseudowords, i.e., the participant needs to read aloud test stimuli as accurately and fast as possible. The test included 60 stimuli where 20 were regular words, 20 irregular words and 20 pseudowords. In addition to regularity, test stimuli varied in lexicality, frequency, and length. Participants had a training session, which included 8 stimuli. For the final score, errors made in the reading of test stimuli and time spent for reading were taken into account.

The test for reading comprehension was taken from Saraiva, Moojen and Munarsk (2006). The test is based on expository texts, which are organized according to the school age. These texts are used by educational psychologists and speech therapists to assess fluency and reading comprehension of students with learning and reading difficulties. Each text is accompanied by a respective illustration, which helps to trigger students' prior knowledge of the topic of the text. The test measures speed of silent and oral reading (number of words read per minute) and assesses reading comprehension by means of 10 comprehension questions.

6.4.2.2 Writing skills

Writing skills of participants were measured by three tests. In the first one, they performed a dictation of isolated words, which assessed participants' orthographic accuracy (Moojen, 2009). The dictation contained 50 words, which were balanced according to orthography and familiarity. Participants heard the tester say one word at a time (when necessary it was repeated) and they had an A4 blank paper to write the words dictated in a column. They wrote in pencil so that they could use an eraser when they needed to correct a word. All errors were calculated based on phoneme-grapheme conversion, contextual rules, and arbitrary rules (word irregularities), thus establishing means and standard deviations for each age level.

In the second test, participants' speed of copying a text was assessed. For this test, the previously read text was used (Saraiva et al., 2007). Participants were given three minutes to copy as many words as they could. They should copy any part of the text exactly as the text was, without skipping words or substituting them. The number of correctly copied words was calculated as well as the number of letters written per minute. Based on the means for each age group, the tester could conclude whether participants were at, below, or above grade level.

Finally, participants produced a text based on a sequence of images that make up a story (Salles, 2005). Participants received a comic strip printed on A4 paper in black and white and were asked to write a story describing the situations displayed on the images. There were no time limits and no size limits. Therefore, participants decided when they the story was ready. For this kind of test, there is no clear objective analysis of the output. The tester counted the number of written words and checked grammar, vocabulary, and punctuation. The tester also assessed participants' ability to produce a text with the beginning, middle and end of the story. Each participant received feedback in a written form on his/her text production.

6.4.3 The experimental task

The experimental task was also based on the active-passive sentence alternation with an unrelated active voice and passive voice structure, the one used in Study I. Due to the high costs of conducting an fMRI experiment and the shortage of funding resources, scanner sessions had time restrictions and as a result, the number of participants had to be reduced. Additionally, given that children with dyslexia from Study I demonstrated cumulative syntactic priming effects for passives only for the first two repetitions, during the discussions with professors Augusto Buchweitz, Katrien Segaert, and Mailce Borges Mota, it was decided to reduce the experimental task from Study I with the conditions for the fMRI data collection. Consequently, the experimental task for Study II was shorten from 200 to 63 sentences.

The fMRI experiment contained thirty passive sentences presented in 10 mini-blocks of 3 sentences each and thirty-three filler sentences presented in mini-blocks varying from 2 to 4 sentences each. Filler sentences were distributed across actives with transitive verbs (18 sentences) and with intransitive verbs (15 sentences). In order to assess reading comprehension, half of passive mini-blocks were followed by a yes-no comprehension question referring to the last sentence (total of five questions for the passive condition). Moreover, participants had to answer five comprehension questions relative to active sentences that were pseudorandomized and could appear after the 1st, 2nd or 3rd sentence of a mini-block. Half of the comprehension questions had the answer *yes* and the other half corresponded to the answer *no*. Participants did not receive any feedback, neither on answers nor on their overall performance by the end of the experiment. An example of a block of sentences in passive voice is presented next:

A chave foi achada pela irmã. (The key was found by the sister.)
O porco foi achado pelo dono. (The pig was found by the owner.)
A bolsa foi achada pela babá. (The bag was found by the nanny.)

Question: *A babá achou a bolsa?* (Did the nanny find the bag?)

The experimental task was divided into two lists with approximately the same number of sentences (five mini-blocks of passives and five mini-blocks of fillers). The presentation of mini-blocks of passive sentences was intermixed with the presentation of filler mini-blocks. First, a fixation cross appeared in the center of the screen before every sentence for a fixed time (see Figure 6.1). This time varied from 1000ms to 1750ms, i.e., fixed time of 1000ms, 1250ms, 1500ms, and 1750ms. After this fixed interval, the first word of a sentence replaced the fixation cross, and the following words of a sentence appeared on the screen after pressing the pad, thus, substituting the previous one. Put another way, the experiment implemented the center non-cumulative self-paced reading paradigm. After each mini-block, there was a fixed-time pause of 7000ms.

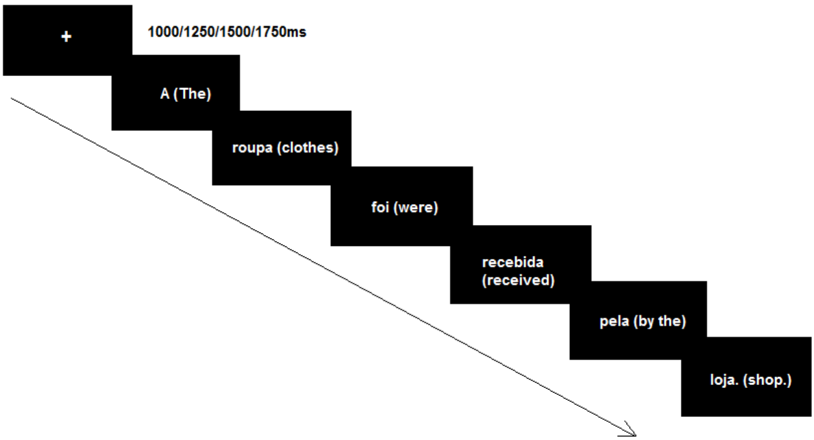

Figure 6.1. Experimental design of a passive sentence presentation (Study II).

Experimental stimuli were presented as a white text on a black background in the center of the screen: instructions written in Arial, bold, 20, sentences in Arial, bold, 40, and questions in Arial, bold, 24. Inside the scanner, participants held two pads: in the left hand to the answer *correct* and in the right hand to the answer *incorrect*. In order to remind the participants about the answer options, each comprehension question was accompanied by the words *correct* located in the left corner of the screen and the word *incorrect* in the right one. There was no fixed time for the response. Reading time (RT) for each word was recorded, i.e., the time between the word presentation and the space bar press, and these behavioral data were used for the statistical analysis.

Although it was self-paced reading, each list had a limited time for performance, 10 minutes, and there were two reasons for that. First of all, the high costs of scanner sessions had to be equally divided among the participants. Second, the fMRI scanner does not run sessions longer than 10-11 minutes. The time of each experimental list was calculated based on the average reading times from Study I, where the mean reading time for sentences was 14 seconds and for questions – 5 seconds. Overall, the total time of the experimental task was 20 minutes plus a short interval between two lists.

6.5 RESULTS

Twelve participants of the present study were selected from the group of children that had been diagnosed with dyslexia by *Projeto ACERTA*. As has been previously informed, the fMRI data of only eight participants were analyzed. Due to the extreme head movements of the other four participants, it was impossible to obtain reliable results based on their fMRI data. Nevertheless, it was decided to include the analysis of the behavioral data of both group compositions with twelve and eight participants for more accurate inferences. Taking into account that syntactic priming results in language comprehension are less consistent than in production, it was expected to see less clear evidence for syntactic priming in a small group with eight participants (Ledoux et al., 2007). The results of the behavioral data obtained from twelve participants are presented first (6.5.1). Then, the results of the behavioral data of eight participants, whose fMRI data were included, are presented (6.5.2). Finally, the results of the fMRI data analysis are reported (6.5.3).

Importantly, in Study II the same data pre-processing of Study I were conducted in relation to the behavioral data, i.e., reading times. First, all impossible values (under 150ms) were removed as these might be due to some accidental responding. Then, means and standard deviations for each word of a sentence were calculated and outliers with values, which were beyond the Mean±1,5SD values, were removed. This data preprocessing was conducted for each group sample separately, i.e., for a group with twelve participants and for a group with eight participants. It is important to clarify that no participants were excluded based on their accuracy performance.

6.5.1 Analyses of the behavioral data from 12 participants

The experimental task output provides the accuracy data regarding the comprehension questions and the data with reading times for each word of a sentence. First, the accuracy data for each participant are presented (6.5.1.1). Then, statistical analyses of processing passive and active sentences are detailed in sections 6.5.1.2 and 6.5.1.3, respectively.

6.5.1.1 Comprehension question accuracy

As the number of comprehension questions was limited, only ten questions, the analysis was not split based on each condition. There were five questions referring to passive sentences and five questions based on fillers. Examining the number of correctly answered comprehension questions reported in Figure 6.2, there were only two participants that scored 50% or below, who would have been considered as outliers and would have been excluded from further analysis if there had been more participants. Two participants scored 60% and 70%, respectively. Overall, the majority of the group scored 80% or above with the group mean accuracy of 78%.

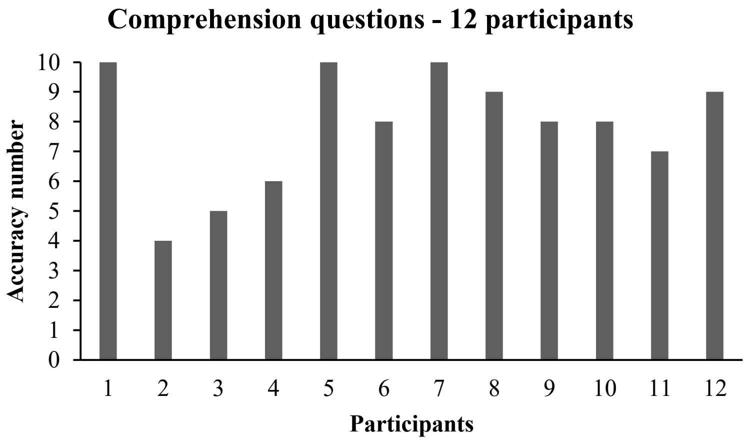

Figure 6.2. Number of accurately responded questions per participant (Study II).

6.5.1.2 Analyses of passive sentence processing

Figure 6.3 reports mean reading times of each word in a sentence within a mini-block. Again, the region of interest for the analysis is word 3, word 4, and word 5. These three words were analyzed as the critical region based on the total reading time. From Figure 6.3, it is possible to observe some syntactic priming effects locally for word 4, the repeated verb, and spill-over effects for word 5. Reading times for word 1, word 2, word 3, and word 6 are very close across all sentence repetitions.

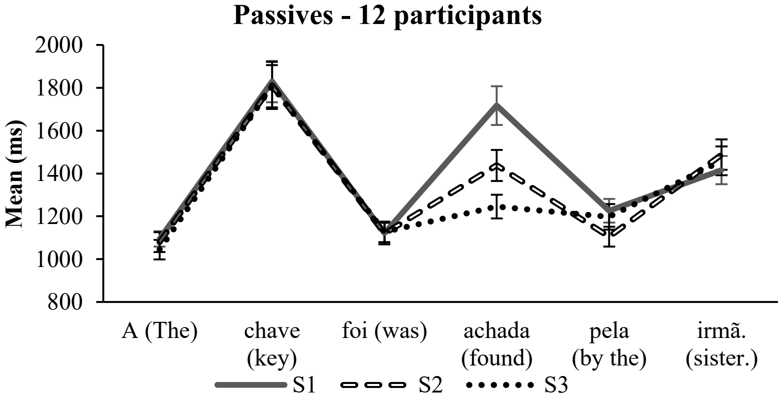

Figure 6.3. Mean reading times for passive sentences (Study II).

Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, and S3 – the last, the third sentence.

Figure 6.4 shows means of reading times (RTs) of the critical region per sentence. It is possible to observe some reduction from sentence 1 to sentence 3. The results of the rANOVA indicated a significant main effect of sentence repetition ($F(2,20)=10.42$, $p=.001$). The follow-up analysis of the Bonferoni post-hoc test revealed a significant difference in means between sentence 1 and sentence 2 ($p=.022$), sentence 1 and sentence 3 ($p=.012$). There was not significat difference between sentence 2 and sentence 3 ($p=.559$).

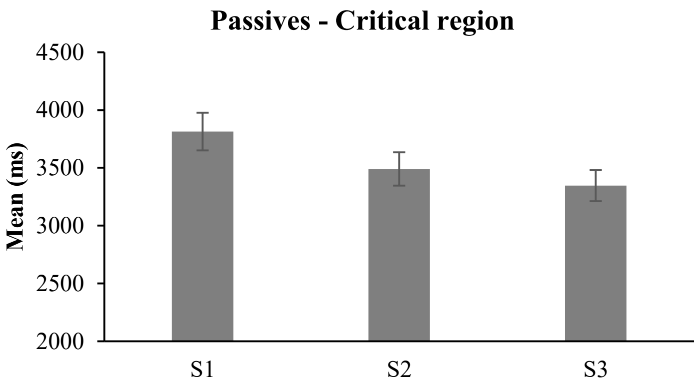

Figure 6.4. Mean reading times for the critical region of passive sentences (Study II).

Note. Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, and S3 – of the last, the third sentence.

As mentioned above, it is possible to conclude from Figure 6.3 that priming effects are all about the main verb (word 4) and some spill-over effects for word 5. Therefore, the data of these words were subject to further analyses.

Figure 6.5 shows means of reading times (RTs) of word 4, where a clear decline of RTs is possible to observe from sentence 1 to sentence 3. The results of the rANOVA indicated a significant main effect of sentence repetition ($F(2,22)=20.41$, $p<.001$). The follow-up analysis of the Bonferoni post-hoc test revealed a significant difference in means between sentence 1 and sentence 2 ($p=.006$), sentence 1 and sentence 3 ($p=.001$). Moreover, there is a significant difference in RTs between sentence 2 and sentence 3 ($p=.019$).

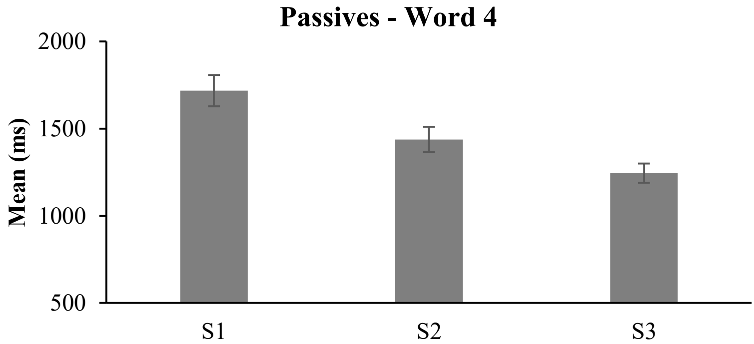

Figure 6.5. Mean reading times for word 4 of passive sentences (Study II).
Note. Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, and S3 – of the last, the third sentence.

Figure 6.6 shows means of reading times (RTs) of word 5, where a possible reduction in RTs is observed from sentence 1 to sentence 2, but then followed by an increase in sentence 3. The results of the rANOVA indicated a significant main effect of sentence repetition ($F(2,22)=3.73$, $p=.040$). The follow-up analysis of the Bonferoni post-hoc test revealed a difference approaching significance in means between sentence 1 and sentence 2 ($p=.054$). There was no significant difference between sentence 1 and sentence 3 ($p=1.00$) and sentence 2 and sentence 3 ($p=.172$).

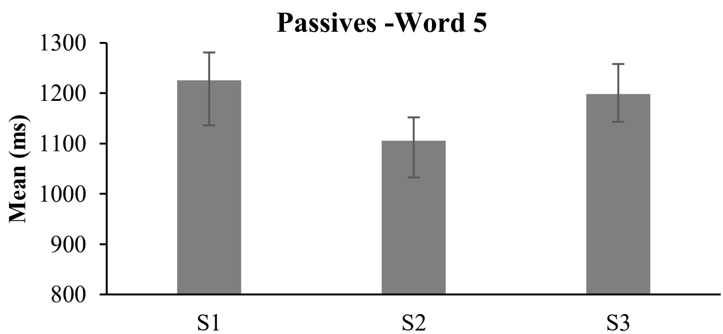

Figure 6.6. Mean reading times for word 5 of passive sentences (Study II).
Note. Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, and S3 – of the last, the third sentence.

6.5.1.3 Analyses of active sentence processing

Figure 6.7 shows mean RTs per word for each active sentence within a mini-block. Observing the way dyslexics processed active sentences, it is possible to see reduction in RTs of the verb (word 3) from sentence 1 in comparison to other three sentences. Figure 6.8 present the means of word 3 per sentence, which also confirms this observation. Although there is a slight decrease in RTs from sentence 1 to sentence 4, the biggest difference seems to occur between sentence 1 and sentence 2. The results of the rANOVA indicated a significant main effect of sentence repetition ($F(3,33)=4.55$, $p=.009$). The follow-up analysis of the Bonferoni post-hoc test revealed the only significant difference between sentence 1 and sentence 4 ($p=.002$). No other mean comparisons were significant: sentence 1 and sentence 2 ($p=.329$). sentence 1 and sentence 3 ($p=.261$), sentence 2 and sentence 3 ($p=1.00$), and sentence 2 and sentence 4 ($p=1.00$).

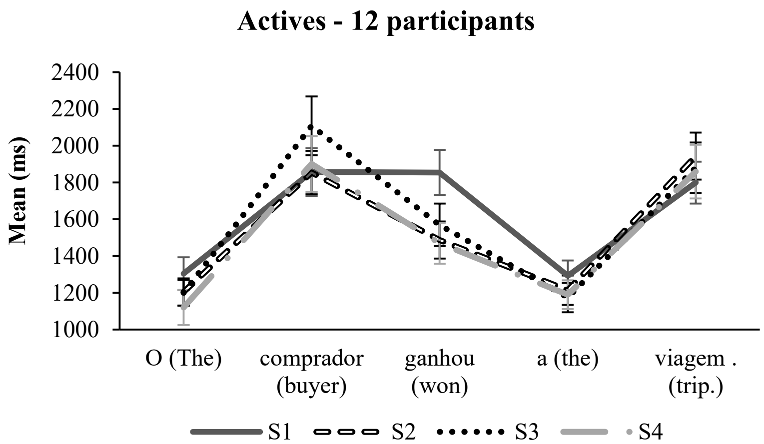

Figure 6.7. Mean reading times for active sentences (Study II).

Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, and S4 - the last, the fourth sentence.

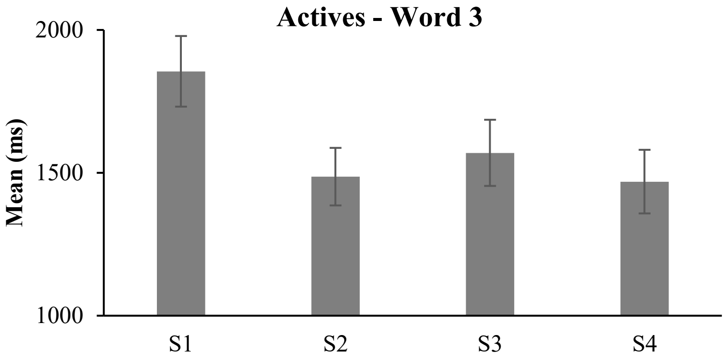

Figure 6.8. Mean reading times for the word 3 of active sentences (Study II).
Note. Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, S3 – the third sentence, and S4 - the last, the fourth sentence.

All in all, the above results go in line with the general hypothesis of the present doctoral dissertation for syntactic priming, i.e., more significant priming effects for passives rather than actives. However, these results were obtained from the whole sample of dyslexics. In order to verify how these priming effect correlate with brain activation in dyslexics, it is commonsensical to report the behavioral syntactic priming results of the group sample whose fMRI data were included for analysis. These results are presented next.

6.5.2 Analyses of the behavioral data from 8 participants

The experimental task output provides the accuracy data regarding the comprehension questions and the data with reading times for each word of a sentence. First, the accuracy data for each participant are presented (6.5.2.1). Then, statistical analyses of processing passive and active sentences are detailed in sections 6.5.2.2 and 6.5.2.3, respectively. Finally, the results of the fMRI data analysis are reported (6.5.2.4).

6.5.2.1 Comprehension question accuracy

The number of correctly answered comprehension questions varied across participants (Figure 6.9). The two participants that scored 50% or below and the two participants that scored 60%-70% remained in the group. The other four participants score 80% or above with the group mean accuracy of 74%.

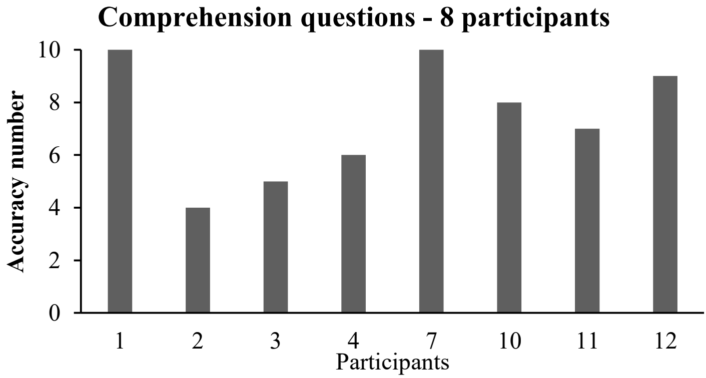

Figure 6.9. Number of accurately responded questions per participant (Study II).

6.5.2.2 Analyses of passive sentence processing

Figure 6.10 reports mean RTs of each word in a passive sentence for eight participants. The same analyses that were conducted in relation to the data of twelve participants took place, i.e., the data of the critical region, and word 4 and word 5 were subject to further investigation. From Figure 6.10, it is possible to observe a similar decrease in RTs for word 4 and a slight decrease for word 5. Reading times for word 1, word 2, word 3, and word 6 look remarkably similar across all sentence repetitions.

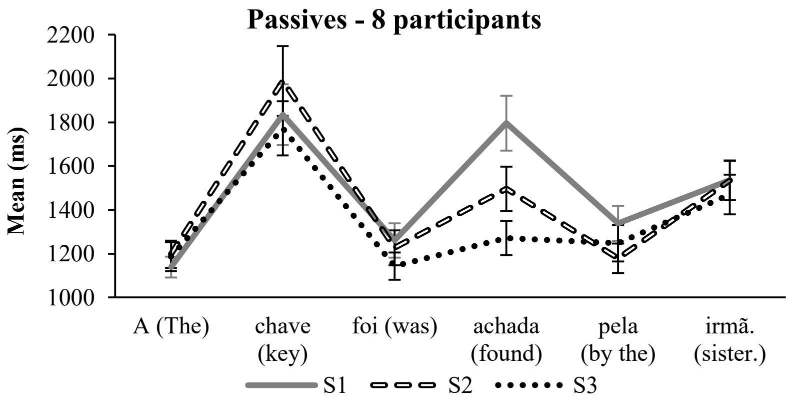

Figure 6.10. Mean reading times for passive sentences (Study II).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, and S3 – the last, the third sentence.

From Figure 6.11, it is possible to see how dyslexics processed the critical region per sentence. There is a gradual reduction from sentence 1 to sentence 3, though the larger difference in RTs is between sentence 1 and sentence 2. Mauchly`s test for the critical region indicated that the assumption of sphericity was violated, $\chi2$ (2)= 7.33, $p<.05$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .59). The results of the rANOVA with a Greenhouse-Geisser correction indicated a significant main effect of sentence repetition ($F(1.17,8.21)=6.85$, $p=.027$). The follow-up analysis of the Bonferoni post-hoc test showed a significant difference in means between sentence 1 and sentence 3 ($p=.006$), but not between the comparisons of sentence 1 and sentence 2 ($p=.255$), and sentence 2 and sentence 3 ($p=1.00$).

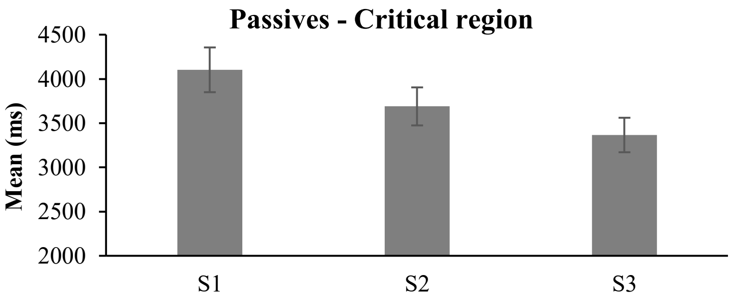

Figure 6.11. Mean reading times for the critical region of passive sentences (Study II).

Note. Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, and S3 – of the last, the third sentence.

From Figure 6.10, which shows how participants processed the whole sentence, the data suggest that priming effects are all about the main verb (word 4) and some possible spill-over effects are present for word 5.Therefore, the data of these words separately are subject to further analyses.

Figure 6.12 reports means of RTs of word 4 for each sentence of a mini-block. These data indicate a gradual decline of RTs from sentence 1 to sentence 3. Mauchly`s test for word 4 indicated that the assumption of sphericity was not violated, $\chi2$ (2)= 3.11, $p>.05$. The results of the rANOVA revealed a significant main effect for sentence repetition, $F(2,14)=17.72$, $p<.001$. The Bonferoni post-hoc test suggested a significant difference in means between sentence 1 and sentence 3 (p=.003), sentence 2 and sentence 3 (p=.009), but not between sentence 1 and sentence 2 (p=.084).

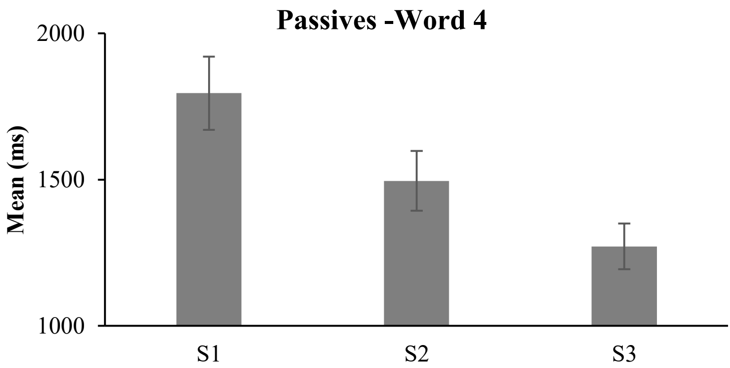

Figure 6.12. Mean reading times for word 4 of passive sentences (Study II). *Note.* Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, and S3 – of the last, the third sentence.

Figure 6.13 shows mean RTs for word 5 with a possibly significant reduction in RTs between sentence 1 to sentence 2, then followed by an increase in sentence 3. The results of the rANOVA indicated a significant main effect of sentence repetition ($F(2,14)=3.91$, p=.045). The follow-up analysis of the Bonferoni post-hoc test revealed the only significant difference in means between sentence 1 and sentence 2 (p=.018). There was no significant difference between sentence 1 and sentence 3 (p=.426) and sentence 2 and sentence 3 (p=.104).

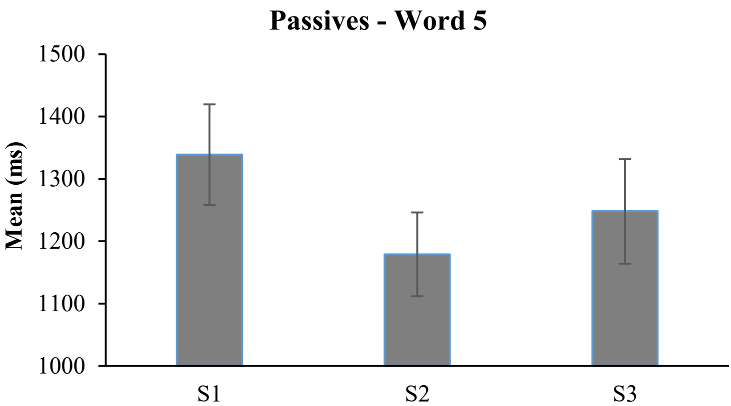

Figure 6.13. Mean reading times for the word 5 of passive sentences (Study II). *Note*. Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, and S3 – of the last, the third sentence.

6.5.2.3 Analyses of active sentence processing

Figure 6.14 reports mean RTs per word for each active sentence within a mini-block. Based on this graph, it is possible to see some significant reduction in RTs only for the verb (word 3) of sentence 1 in relation to other three sentences. Figure 6.15 presents the means of word 3 per sentence, supporting this evidence. Mauchly`s test for word 3 indicated that the assumption of sphericity was violated, $\chi 2$ (5)= 15.72, $p<.05$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .41). The results of the rANOVA revealed no significant main effect for sentence repetition, $F(1.24,8.66)=2.66$, $p=.136$.

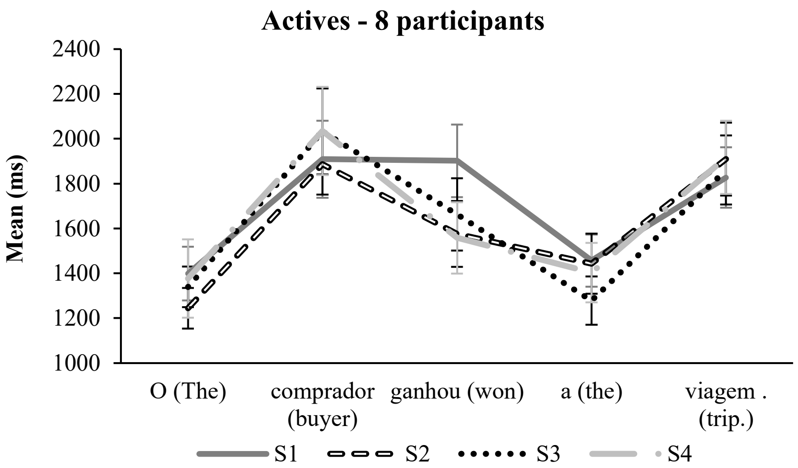

Figure 6.14. Mean reading times for active sentences (Study II).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, and S4 - the last, the fourth sentence.

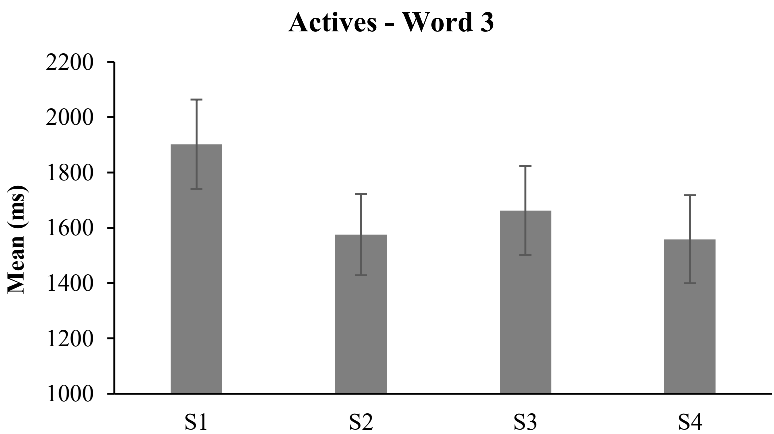

Figure 6.15. Mean reading times for word 3 of active sentences (Study II).
Note. Error bars denote one standard error around the mean. S1 corresponds to the reading time of the first sentence of a mini-block, S2 – of the second sentence, S3 – the third sentence, and S4 - the last, the fourth sentence.

To summarize, the behavioral data were analyzed taking into account the whole sample of participants (N=12) as well as the final sample, which was reduced based on the fMRI data analysis (N=8). The decision to include the analysis of the whole sample was driven by the assumption that a larger number of participants would be more robust and would strengthen the pattern of syntactic priming effects already observed in Study I. Indeed, the results from twelve participants appear to be largely consistent with the results from Study I rather than from eight participants.

The review of results focuses on the analysis of the critical region, word 4 and word 5 of passive sentences. The group of twelve participants showed significant behavioral priming effects in the critical region between sentence 1 and sentences 2 and 3 (p<.05), whereas the group of eight participant had significant behavioral priming effects only between sentence 1 and sentence 3 (p<.05). As expected, the greatest magnitude of syntactic priming concentrated on the verb (word 4). The group of twelve participants showed significant priming effects between sentences 1 and 2, 1 and 3, and 2 and 3 (p<.05) and the group of eight participant demonstrated priming effects between sentences 1 and 3, 2 and 3 (p<.05). Significant spill-over effects for word 5 were identified between sentence 1 and sentence 2 (p<.05) in the group of eight participants, and similar effects approaching significance were observed in the group of twelve participants.

The results for active sentences are of considerable interest. It is important to point out that the verb in active sentences were also repeated within a mini-block, similar to blocks of passives. Therefore, the same results would be expected for active and passive sentences when considering that only lexical overlap between sentences was responsible for differential processing of target sentences. However, this was not the case. The group with twelve participants as well as the group with eight participants processed actives to a different extent. The only significant effects of syntactic priming were found between sentences 1 and 4 for the group with twelve participants. The group with eight participants showed no syntactic priming effects at the verb.

Having reviewed the behavioral results supporting syntactic priming effects for passives and differential processing between actives and passives, the present study also attempted to provide insights into the neuronal underpinnings of syntactic priming during sentence comprehension. Thus, the analysis of the fMRI data is reported next.

6.5.3 Analysis of the fMRI data from 8 participants

Before reporting the results of the fMRI data analysis, it seems valuable to explain how these data were pre-processed for further subject and group level analyses, thus demonstrating all the complexity involved in the analysis. Therefore, this section, first, presents the sequence of the pre-processing step. Then, the subject level analysis is reported. Finally, the group analysis is described and the results are disclosed. I must give credit to the team at *Instituto do Cerebro (InsCer)* that carried out a careful analysis of the fMRI data under the supervision of professors Alexandre Franco and Augusto Buchweitz. Additionally, I received additional support from Kirsten Weber, a researcher at the MPI, in analysing and interpreting the fMRI results.

In light of the behavioral findings, which revealed significant syntactic priming effects at the main verb (word4), the fMRI data were analyzed in relation to this word. Considerable complexity to this analysis was caused by the fact that the experimental task employed a self-paced reading paradigm. Participants processed sentences at their own speed and, consequently, word 4, at a different time course of the experiment, i.e., the words of the sentences were not time locked. This means that the rate of presentation of stimuli depended on reading speed of each participant, thus leading to different timings and durations of stimuli.

In this context, the first step was to inspect the behavioral data in order to retrieve timing information for word 4. Distribution of onset latencies, i.e., the time when word 4 appeared on the screen, and durations, i.e., the interval between the appearance of word 4 and the time when the participant pressed the button to proceed with the next word of a sentence. For passives, each mini-block had three values for onset latencies and three values for durations, whereas for actives, there were from two to four onset latencies as well as from two to four values for durations. With the help of the R script, the data were retrieved from the files and coded according to condition (passives or actives) and sentence repetition (sentence 1, sentence 2, sentence 3, or sentence 4). This timing information was essential in order to identify the fMRI images according to each condition and sentence repetition.

In the first stage of the fMRI data pre-processing, procedures related to removing artifacts unrelated to the experimental task were applied. The fMRI data were preprocessed using the AFNI program (Cox, 1996). Images were corrected for slice timing acquisition, i.e., differences in image acquisition time between slices. The number of slices was 29, which were acquired in interleaved ascending order

(1:2:29, 2:2:29) with a repeat time (TR) of 2000ms. Images were also corrected for head motion using a 6mm with a full-width half maximum (FWHM) Gaussian smoothing kernel. Figures 6.16 and 6.17 display examples of the outputs with motion estimation as plots of translation and rotation. Trials with discrepant values of movement (> 0.9mm) were excluded from the data. As a result, the data of four participants had to be excluded due to excessive head movements.

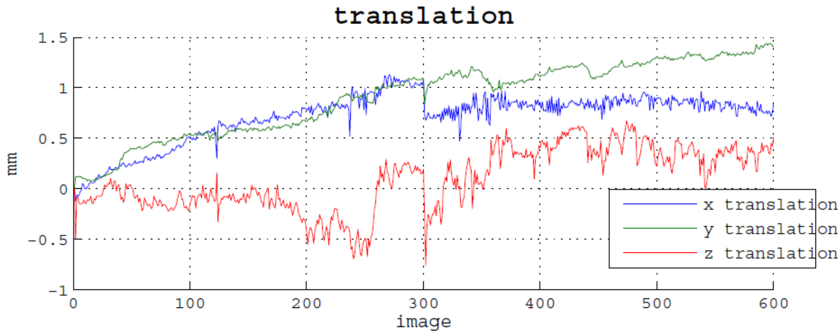

Figure 6.16. An example of the translation output from the realignment step.
Note. Translation corresponds to the distance moved along a specific axis. The standard (x,y,z) coordinate system is used in fMRI analyses. The x axis runs through the participant's ears from left to right. The y axis runs from the back of the head to the forehead of the participant. The z axis runs from the feet to the top of the head (Ashby, 2011).

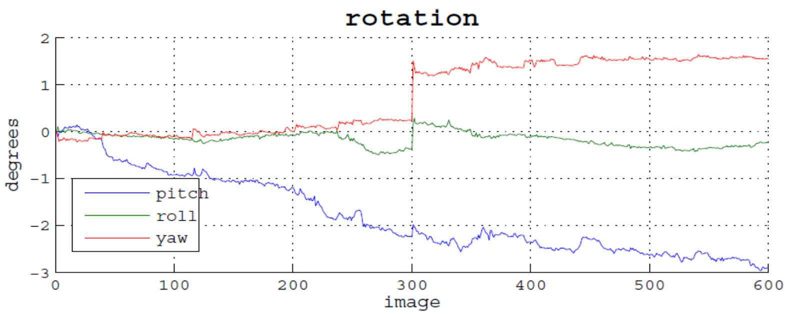

Figure 6.17. An example of the rotation output from the realignment step.
Note. Rotation corresponds to the angle of rotation along a specific axis.The standard (x,y,z) coordinate system is used in fMRI analyses. Pitch is an up or down rotation about the x axis. Roll is a rotation about the y axis. Yaw is a side-to-side rotation the z axis (Ashby, 2011).

The next step, co-registration, refers to the realignment of the mean fMRI images to the structural image, i.e., functional activations are overlaid onto a participant`s anatomical brain image. Figure 6.18 shows the output of this step. When moving the lines, it is possible to see the same location in the functional images and the structural images and check whether the co-registration worked well.

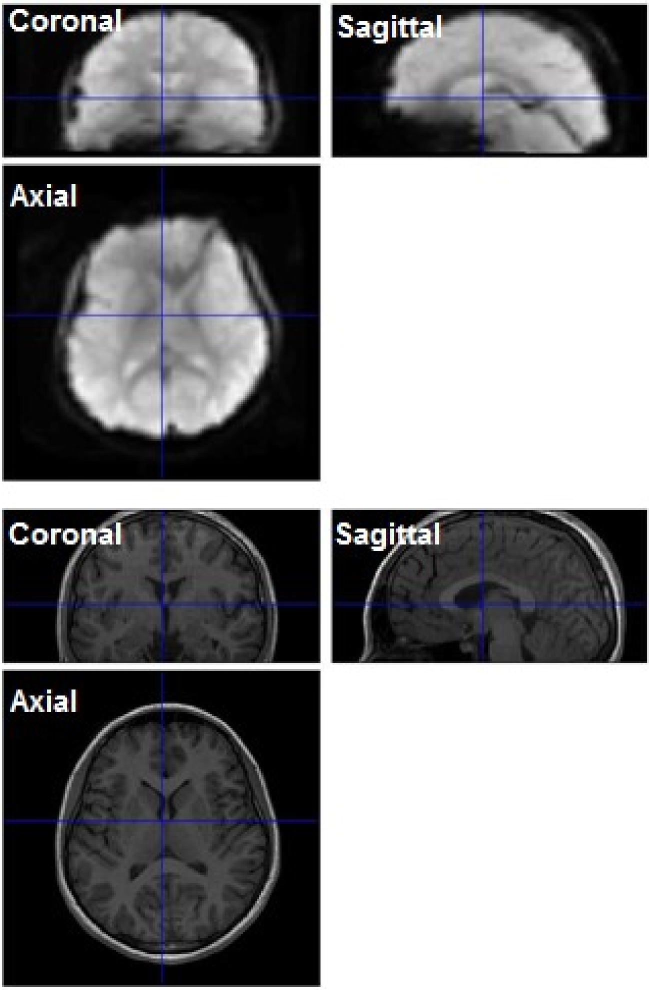

Figure 6.18. An example of the output of the co-registration step.
Note. Above are the coronal, axial, and sagittal slices of the co-registered mean fMRI image, and below are the structural images with the respective slices.

In addition, images were submitted to a non-linear spatial normalization for voxel model 3.0 x 3.0 x 3.0 mm (HaskinsPedsNL model for pediatric brains), which is an important process when analyzing group data. The aim of spatial normalization is to establish a correspondence between the brains of various participants to a standard template. Finally, spatial smoothing was applied to the normalized images. Smoothing helps to filter out high-frequency information and reduce noise in the image. Moreover, due to the fact that all regions do not have the same size, effects of anatomical variability may be reduced. Selecting a specific region of interest will help to optimize sensitivity to that region (Celesia & Hickok, 2015). The region of interest (ROI) in the present study was the left inferior frontal gyrus (LIFG) (coordinates: x = -44, y = 24, z = 2 based on Montreal Neurological Institute, MNI) and it was expected to see changes in brain activation in this region because the LIFG, commonly known as Broca`s area (BA 44/45), is particularly implicated in sentence comprehension and integration of syntactic information (Friederici, 1998; Hagoort, 2007). Nevertheless, the whole brain analyses were conducted.

Once the pre-processing of the individual data was finished, the subject level analysis was held. In this step, the design and contrasts were informed. All information retrieved from the behavioral data such as conditions, onsets and durations was included. For the comparison between the activation for passive verbs and active verbs, the specific contrast was entered. For passives, the following contrasts were specified: verb 3 (3rd sentence repetition) > verb 1 (1st sentence repetition), verb 3 (3rd sentence repetition) > verb 2 (2nd sentence repetition), and verb 2 (2nd sentence repetition) > verb 1 (1st sentence repetition). For actives, the following contrasts were considered: verb 4 (4th sentence repetition) > verb 1 (1st sentence repetition), verb 4 (4th sentence repetition) > verb 2 (2nd sentence repetition), verb 4(4th sentence repetition) > verb 3 (3rd sentence repetition); verb 3 (3rd sentence repetition) > verb 1 (1st sentence repetition), verb 3 (3rd sentence repetition) > verb 2 (1st sentence repetition); and verb 2 (2nd sentence repetition) > verb 1 (1st sentence repetition). Figure 6.19 displays an example of the output of conditions and contrasts at the individual subject level.

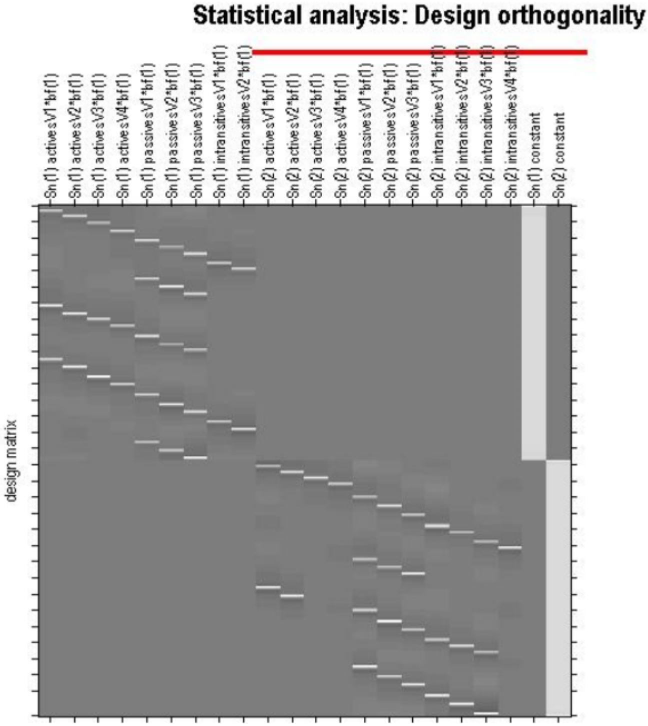

Figure 6.19. An example of the output of the analysis at the group level per condition.

The data from the subject level analysis were submitted to the group level analysis. Initial analyses included regressors for passive verbs 3 and 1, and for the fixation cross condition from convolution of a canonical hemodynamic response function, as implemented in AFNI (Cox, 1996). Rest periods of 7s were not explicitly modeled. A t-test was used to compare the activation distribution between the two conditions. Then, a random effects model and contrast images for all types of words versus fixation was implemented. To correct multiple comparisons, the program 3dClustSim, which calculates a corrected *p*-value of less than 0.05 for multiple comparisons was used. After the calculation, cluster analyses for $p<0.005$ were performed with a minimum cluster size = 62 voxels (1674 μl). These values represent a corrected analysis for multiple comparisons. The participants` age was a covariate in the analyses to control any effects due to age differences between the participants.

The group results showed increased activation in the LIFG and the left middle frontal gyrus (LMFG) for the first contrast in the passive condition (verb 3 > verb 1). Axial and sagittal images shown in Figure 6.20 indicate this increased activation in the orange cluster.

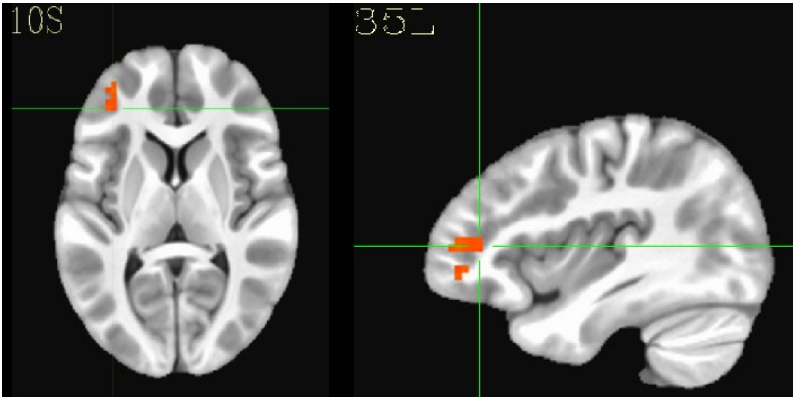

Figure 6.20. Brain activation for the passive verb 3 > verb 1 contrast condition (p<0.005, LIFG coordinates x = -35; y = 37; z = 10; cluster size 37 voxels).

An increased activation in the LMFG was also found in the passive condition for verb 3 > verb 2. Figure 6.20 shows this activation in the orange cluster.

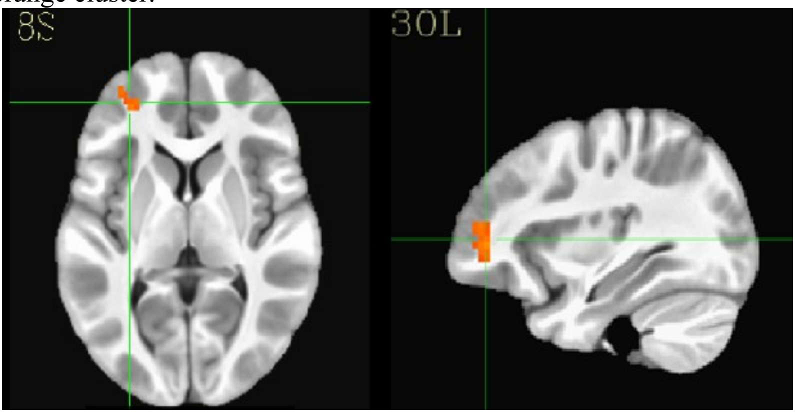

Figure 6.21. Brain activation for the passive verb 3 > verb 2 contrast condition (p<0.005, LMFG coordinates x = -30; y = 44; z = 9; cluster size 45 voxels)

There were no significant differences in activation for the verb 2> verb 1 contrast in the passive condition. Thus, for the passive condition, the only significant priming effects were observed in relation to two contrasts: verb 3> verb 1, and verb 3 > verb 2.

Analyzing the contrasts of the active condition, the following results were obtained. In the contrast verb 4>verb 1, there was a significant decrease in activation in the anterior cingulate cortex (ACC), which is the frontal part of the cingulate cortex. Figure 6.22 shows this deactivation in the blue cluster. Moreover, no significant differences for any other contrast combinations were observed (verb 4 > verb 2, verb 4 >verb 3, verb 3 > verb 1, verb 3> verb 1, verb 2 > verb 1).

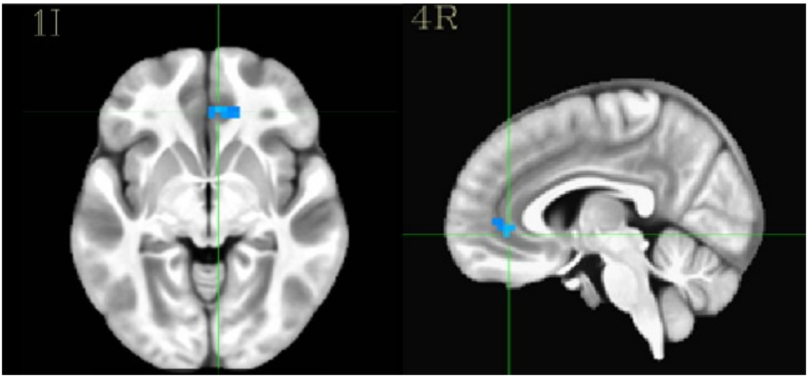

Figure 6.22. Brain activation for the active verb 4 > verb 1 contrast condition ($p<0.005$, ACC coordinates x = 4; y = 36; z = 0; cluster size 21)

All in all, the above reported results for the behavioral data and the neuroimaging data suggest some important commonalities. These commonalities are discussed in the next section.

6.6 DISCUSSION

The main objective of the present doctoral dissertation was to investigate sentence processing in dyslexics through the syntactic priming paradigm and reveal whether this special population benefits from these effects when processing complex structures like the passive voice. In addition to sentence processing at the behavioral level, syntactic priming effects in Study II were also explored at the neuronal level. With the use of the neuroimaging technique (fMRI), it was possible to identify the brain regions that were more engaged during on-line processing of passive and active sentences. The present section discusses both the behavioral and neuronal syntactic priming effects detected in Study II and explains the data commonalities in light of the literature.

As already said, due to the funding limit available to conduct an fMRI experiment, only twelve participants were selected to take part in Study II. Similarly to Study I, in Study II participants read short sentences and answered comprehension questions, though the length of the experimental task was significantly reduced (only 63 sentences instead of 200). The primary step in analyzing the behavioral data was to verify whether dyslexics had read and comprehended sentences by calculating the number of accurately responded questions. Importantly, not all mini-blocks contained a comprehension question due to the time limit of the experiment (there were only ten questions in the fMRI version of the experiment, instead of the 40 questions of the behavioral experiment).

Although there were only ten comprehension questions as a guarantee that dyslexics paid attention to the task and processed sentences accordingly, participants' responses to these questions were analyzed in order verify whether there was any participant with low level of accuracy. As a result, two participants out of twelve performed within the 50% threshold, thus suggesting that slowed processing speed affected dyslexics' comprehension and their answers were at random. Their slowed processing was due to inefficient word recognition, which has been shown to have a strong impact on reading comprehension (Jenkins et al., 2003; Landi, 2010). Despite their performance, these participants were not excluded from the final sample due the already small sample size whose fMRI data were suitable for further analysis. If these two participants had been excluded, the final sample would have consisted of only six dyslexics.

In addition to the analysis of the behavioral data of the final sample (N=8), an analysis of the behavioral data of all twelve participants was conducted. The overall results showed that the group of twelve participants showed stronger syntactic priming effects for passives in comparison to the group of eight participants. In addition, the group of twelve participants showed significant priming effect for actives between sentence 1 and sentence 4. The results of the group with twelve participants were similar to the results of Study I with the dyslexic group of 20 participants. Therefore, the number of participants in the study investigating syntactic priming effects in language comprehension, which are more subtle than in language production, should count with at least 20 participants.

The parsimonious analyses of the behavioral data of eight dyslexics showed significant priming effects for the critical region of passives and especially stronger effects for word 4. These findings partially answer the first research question (RQ 1) about syntactic priming effects for passive sentences. Moreover, priming effects for word 4 were cumulative where response times decreased significantly from sentences 1 to sentence 2 as well as from sentence 2 to sentence 3. These findings answer the second research question (RQ 2) and are in line with Hypothesis 2 posed in section 7.1. In addition, there were significant spill-over effects on word 5. This suggests that effects were so strong on word 4 that they influenced the next word 5 (Traxler et al., 2014).

The comparison of syntactic priming effects between passive and active structures was not the primary goal of this study. However, when inspecting how dyslexics processed these distinct syntactic structures, the difference in the magnitude of syntactic priming effects was observed. The effects were strong for passives, whereas for actives, no significant priming effects were observed. These findings add additional evidence to the answer for the first research question (RQ 1) by comparing the effects between two conditions. These findings are consistent with the inverse frequency effect (Ferreira & Bock, 2006). The inverse frequency effect suggests that the frequency of syntactic structures influence syntactic processing in a primed condition and individuals' processing benefits more from infrequent or poorly developed structures. Thus, the passive voice, being an infrequent and more complex structure than the active voice, leads to more priming effects, whereas effects for the active voice tend to be either absent or small. The inverse frequency effect for the passive and active alternations is reported frequently in the literature on syntactic priming (Bock, 1986; Bock & Loebell, 1990; Hartsuiker & Kolk, 1998; Segaert, Menenti, Weber, & Hagoort, 2011).

Moreover, taking into account that passives impose higher syntactic processing demands due to the complexity of the structure and effects for passives were stronger, the results suggest that dyslexic, compared to non-dyslexic controls, experienced greater difficulties in processing passive sentences and that, through syntactic priming, larger changes in mental representations of this structure occurred leading to larger facilitation effects. In other words, dyslexic participants had a weakness in processing the passive voice structure, but due to its repeated presentation, they implicitly acquired abstract representations of this complex structure. In support of this acquisition, long lasting and cumulative syntactic priming effects were detected for passives and not for actives. Therefore, these findings provide additional support to the account of implicit learning as a mechanism driving syntactic priming (Chang et al., 2006; 2000). This mechanism was visible in the magnitude of the syntactic priming effects observed in the dyslexic participants of Study II.

Neuroimaging studies which implemented the syntactic priming paradigm have attempted to provide consistent evidence for the neuronal correlates of syntactic priming effects (Menenti et al., 2011; Noppeney & Price, 2004; Segaert et al., 2012; Weber & Indefrey, 2009). The manifestation of priming effects in fMRI studies is detected through the adaptation or change of neural responses (BOLD) when a stimulus is repeated. This phenomenon can be either enhanced (repetition enhancement) or reduced (repetition suppression) (Henson, 2003; Segaert, Kempen, Petersson, & Hagoort, 2013). In comprehension as well as production fMRI studies, behavioral syntactic priming correlates with reduced neuronal activity.

In Study II, the extent of fMRI adaptation to repetition of the verb in actives and passives was measured. These fMRI results are discussed in relation to the behavioral results where strong priming effects were observed for passives rather than actives. Similarly to the behavioral results, the activation patterns in the dyslexic brain were distinct between these two conditions.

In the contrasting comparisons for passives (verb 3> verb 1, verb 3>verb2), the enhancement effect was present in the left inferior frontal gyrus (LIFG) and the left middle frontal gyrus (LMFG). The repetition enhancement, i.e., increase of neural responses from primed stimulus, especially in the LIFG region was surprising evidence. The manifestation of syntactic priming was expected to be observed in a form of repetition suppression, i.e., decreased neural responses for primed stimulus, as a result of behavioral facilitation effects of priming (Henson, 2003; Segaert et al., 2013). Therefore, these findings contradict my prediction posed in Hypothesis 3 about reduced brain activation in a syntactic processing region (LIFG) in relation to the primed passive structure.

Although the repetition suppression effects are clearly associated with facilitated and automatic responses for priming stimuli, it is difficult to be conclusive about repetition enhancement effects. In a review of fMRI studies, Segaert and colleagues (2013) provide a number of cognitive mechanisms that may explain these effects. These are “stimulus recognition, learning, expectation, attention and explicit memory” (p.60).

For the dyslexic group under investigation, the most attractive explanation regards learning and the formation of novel networks.

Following this explanation, dyslexics do not have a solid memory representation of the passive voice structure, which is considered a novel stimulus. Through repetition, novel stimuli create new representations where a neural network is built for these stimuli (Henson, 2003; Henson, Shallice, & Dolan, 2000). It takes time to consolidate this information. In contrast, for familiar stimuli, there is an already well-established network, thus leading to repetition suppression. Indeed, assuming that dyslexics were more familiar with active sentences as a more frequent and less complex structure, repetition suppression was observed for the contrast verb 4 > verb 1 in the anterior cingulate cortex (ACC).

The brain regions where the activation was observed corroborate the representative language brain regions accounted in the Memory, Unification and Control (MUC) model proposed by Hagoort (2005). According to this model, the left inferior frontal gyrus (LIFG) and adjacent cortex, including the left middle frontal gyrus (LMFG) are involved in syntactic processing and this region is responsible for integrating syntactic information. The integration process occurs in the Unification component of the model which is responsible for recruiting lexical information and unifying this information into multi-word sentences (Hagoort, 2005). As for the anterior cingulate cortex (ACC), this region is involved in planning and attention control. The Control component of the MUC model accounts for these operations.

Taken together, the above-discussed results aimed at clarifying the relationship between syntactic priming effects at the behavioral level and effects at the neuronal level. In light of reduced reading times for primed passives, it can be concluded that dyslexics are able to overcome difficulties in syntactic processing through repetitive practice. At the neuronal level, this novel formation is associated with repetition enhancement associated the formation of novel networks. These findings might contribute to the area of dyslexia research showing that although dyslexics have a weak syntactic representation, they are apt to acquire these novel representations that allow more rapid processing. In addition, this new representation formation may have a long lasting effect, thus being more beneficial to this special population. Of course, the results from only eight dyslexics cannot be generalized to an entire population of dyslexics. For future fMRI studies, more dyslexic participants should be investigated in order to get data that are more robust. In addition, a comparative analysis with the control group should also provide important insights.

In the next chapter, I report Study III that was conducted with adult dyslexics, native speakers of British English. A similar syntactic priming paradigm was used. Interestingly, Study III shows evidence for syntactic priming effects during sentence comprehension in adult dyslexics. The results of these findings are presented next.

CHAPTER VII
STUDY III: INVESTIGATING SYNTACTIC PRIMING EFFECTS IN DYSLEXIC ADULTS

This chapter reports Study III that was conducted to explore syntactic processing via the syntactic priming paradigm in a dyslexic population consisting of native speakers of English, students of the University of Birmingham, United Kingdom. The dyslexic adults of Study III are considered high achievers. The main objective of Study III was to understand the workings of syntactic processing and elicit whether dyslexic adults also show difficulties at the syntactic level and whether they benefit from the repeated exposure to a complex syntactic structure like the passive voice. Having in mind that a syntactic priming paradigm provides a useful means for probing syntactic representations, the present study investigated how adult dyslexics access representations of passive and active sentences during reading comprehension. The experimental design was similar to that described in Study I and Study II where the focus of investigation was primed passive sentences with actives serving as fillers. There were, though, few alterations in the design. Importantly, the whole experiment was carried out in English.

The present chapter is organized in several sections that describe the methodology adopted for this study together with the results. In section 7.1, the research questions and hypotheses that guided this investigation are outlined. Seeking answers to these questions, the present study employed the research design delineated in section 7.2. Section 7.3 presents a detailed description of the participant population. Section 7.4 explains what instruments were used for the data collection. The following section (7.5) specifies the statistical analysis of the quantitative data and presents the results obtained. Finally, the discussion of the results is presented in section 7.6.

7.1 RESEARCH QUESTIONS AND HYPOTHESES

In seeking to understand better how syntax is processed in the dyslexic population through the syntactic priming paradigm, the central research question that this dissertation addresses is whether dyslexics are susceptible to syntactic priming effects. Taking into consideration the experimental design of Study III, the following secondary research questions were posed:

RQ1: How do adult dyslexics perform on standard language-based tests?

RQ2: Do adult dyslexics and controls have similar performance on standard intelligence tests?

RQ3: Do adult dyslexics show syntactic priming effects for passive sentences? and active sentences?

RQ4: Are syntactic priming effects cumulative?

These research questions posed the following hypotheses:

Hypothesis 1: Adult dyslexics will demonstrate significant difficulties with the tests that assess language-based skills.

The language-based tests were included in order to determine whether dyslexic participants experience problems with language processing. Dyslexics do not only have difficulty in word identification, but they are also deficient in the ability to distinguish and manipulate phonemes (Vellutino et al., 2004). Thus, it is expected that adult dyslexics perform worse overall on language-based tests.

Hypothesis 2: Adult dyslexics and controls will perform equally well on standard intelligence tests.

The intelligence tests were included in order to show that dyslexics' intelligence is preserved as stated in the definition of dyslexia (Vellutino et al., 2004). Importantly, the intelligence tests employed in the present study did not depend on skills and knowledge that are generally acquired through the exposure to reading, thus avoiding underestimation of dyslexics' intelligence. Therefore, it is expected that dyslexics will perform equally well as controls under all intelligence test conditions.

Hypothesis 3: Adult dyslexics will demonstrate significant priming effects for passive sentences, but not for active sentences.

Having in mind that dyslexics are by nature much slower in reading, they have a larger temporal window for processing sentences and as a result, a potentially larger degree for improvement. Therefore, it is expected that their processing of consecutive passive sentences will be modified due to facilitatory effects of syntactic priming. Observing a decrease in reading times, it will be possible to state that it is implicit learning that drives syntactic priming.

Hypothesis 4: Adult dyslexics will show cumulative syntactic priming effects.

In the same vein, dyslexics will demonstrate a greater improvement in reading due to cumulative syntactic priming effects because their temporal window for processing sentences is larger. Attesting cumulative effects where the magnitude of the effects is stronger with each consecutive repetition, additional evidence to implicit learning will be provided.

7.2 RESEARCH DESIGN

In order to address the research questions of the present study, the following design was adopted. The study involved an individual session that was administered at the University of Birmingham. Two experimenters, undergraduate students of the School of Psychology at the University of Birmingham performed the data collection under the supervision of professor Katrien Segaert. The experimental session consisted of three parts that obeyed the following sequence. In the first part, participants who contacted the experimenters were invited for a short interview where they answered questions regarding possible comorbid learning disabilities and other factors like uncorrected sensory impairments (vision, hearing) and use of medication that could affect their performance on the experimental tasks. Participants who met the eligibility criteria were selected for the experiment. Afterwards, they received some introductory information about the study and what they were expected to do.

Upon agreement, the selected participants were introduced to the experiment. They sat at a distance of 40 cm (or comfortable for them) in front of a computer screen and received a short instruction. To familiarize participants with the experimental task, they received a training session, which consisted of two trial mini-blocks. Once they felt comfortable with the experimental procedures, they started the experiment task. The time-course of the experimental task was not limited as participants advanced through the task at their own pace. However, the majority completed the task in approximately 30 minutes. Considering the amount of stimuli, there was a mandatory break of five minutes in the middle of the experiment in order to avoid participants' fatigue and guarantee consistent performance and concentration throughout the experiment. Finally, the third part of the session was dedicated to a series of language and intelligence tasks, which lasted for about one and a half hours. The total time required to complete the experimental sessions was about two hours and all tasks were administered in a one-day visit. At the end of all tasks, participants received a debriefing and also had the opportunity to ask more questions. No feedback was given to the participants on their performance on the tasks.

7.3 PARTICIPANTS

With the use of the digital recruitment notice board of the Research Participation Scheme of the University of Birmingham (https://birmingham.sona-systems.com/), potential participants could read about and sign up for the present experiment. In addition to this, the recruitment was established through on-line social networks and personal networking. Bilingual participants were ruled out as their language processing could be influenced by the second language (Kroll & Bialystok, 2013).

In the final sample of participants, there were forty-one undergraduates and, from these, 20 were dyslexics and 21 pertained to the control group. The mean age of dyslexics at the time of data collection was 20.10 years (*SD*=1.33, *range* = 18-24 years; 15 females). The mean age of controls at the time of data collection was 19.45 years (*SD*=1.73, *range* = 18-25 years; 18 females). All participants reported normal or corrected-to-normal vision and had no history of brain injury. To compensate for their participation, they received either two credits for the course or a cash payment in the amount of £14.00 from the British Academy funding. Participants gave written informed consent and were reassured of confidentiality and their right to withdraw at any time and have their data destroyed. It is important to explain that the experimental design of Study III was approved by the ethical research review team of the University of Birmingham and this study is part of a research project submitted by professor Katrien Segaert at the University of Birmingham, the UK.

7.4 INSTRUMENTS

The experimental task as well as the language and IQ tests were presented on a 22” monitor with an operating keyboard. The experimental task was implemented with the use of the E-Prime 2.0 Professional version, which recorded response time and accuracy data. Moreover, tools like a stopwatch, a voice recorder and a set of nine colored blocks were required for the administration of the Comprehensive Test of Phonological Processing (CTOPP) and Wechsler Adult Intelligence Scale –fourth edition (WAIS-IV).

7.4.1 Standardized tests for the assessment of language-based skills and intelligence

In addition to the experimental task, several tests for the assessment of language and intelligence were administered. Confirming their diagnosis of dyslexia, dyslexics were expected to be less efficient on language-based abilities, but have similar performance on the intelligence tests. Table 7.1 presents a list of these tests in the chronological order of their execution and brief information about each one.

Table 7.1
Standardized tests for the assessment of language and intelligence (Study III)

Test Name	Description
Gray Silent Reading Tests	Read increasingly complex stories and answer questions
Elision*	Remove phonological segment to form new words
Memory for digits *	Repeat strings of spoken numbers
Non-word repetition *	Repeat spoken non-words
Rapid letter naming *∞	Read list of letters rapidly
Phoneme reversal *	Reverse phonemes of spoken non-words into real words
Sight Word Efficiency *∞	Read list of phonetically regular words
Phonemic Decoding Efficiency *∞	Read list of phonetically regular non-words
Test of Irregular Word Reading Efficiency *	Read list of phonetically irregular words
Block design*∞	Reproduce a design with blocks
Matrix reasoning*∞	Complete a matrix with an image from a list
Visual puzzles*∞	Reproduce a puzzle with three parts
Symbol search∞	Search for target symbols
Coding∞	Code a string of numbers
Corsi block tapping task	Reproduce the order of lit up squares

Note. Tests denoted * are terminated following three consecutive errors, and tests denoted ∞ are time controlled and performed as fast as possible. The Corsi block tapping task is terminated following two consecutive errors.

7.4.1.1 Gray Silent Reading Tests (GSRT)

The Gray Silent Reading Tests (GSRT) measure silent reading comprehension ability. These tests can be applied to individuals from 7 to 25 years old. They consist of two equivalent forms with 13 short reading passages each, but only one form is administered to the examinee.

In addition, each reading passage is followed by five multiple-choice questions, which are included in order to check comprehension. Correctly answered questions yield raw test scores. The examinee starts reading short passages with simple plots and then passages gradually increase in length and complexity, thus demanding higher-level inferencing skills. There are no time constraints.

7.4.1.2 Comprehensive Test of Phonological Processing (CTOPP)

In order to assess reading related phonological processing skills of the participants, a series of language tasks (subtests) from the Comprehensive Test of Phonological Processing (CTOPP) were administered. The CTOPP is a published and norm-referenced test, which has received high validity and reliability for its instruments to assess phonological processing skills and identify the individual's deficiency in these skills (Hintze, Ryan, & Stoner, 2003). The CTOPP was chosen, first of all, because it is a widely-used assessment instrument in the area of dyslexia (McLoughlin & Leather, 2013). With the CTOPP, professionals can not only identify dyslexics' phonological weaknesses and strengths, but also document their progress on these skills. Second, the experimenters had access to the test kit and received a special training on the administration and scoring of the CTOPP subtests. Overall, five subtests were selected: elision, memory for digits, non-word repetition, rapid letter naming, and phoneme reversal. A brief description of each is presented next.

7.4.1.2.1 Elision

The elision subtest measures the ability to subtract a phonological segment from a spoken word to form a new word. First, the examinee receives some practice items with instructions. For instance, the examinee hears the word *toothbrush* and is asked to repeat this word. Then, the examinee is asked to say *toothbrush* without the first part of the word *tooth*. If the examinee says *brush,* s/he receives feedback such as *That's right. Let's try the next one.* If the examinee makes an error, s/he receives feedback like *That's not quite right. Toothbrush without saying tooth is brush*. There are three practice items to check whether the examinee understands what s/he is expected to do. Then, three test items follow the practice items that are also accompanied by feedback about the correctness or incorrectness of the response. The subtest becomes more difficult when the examinee needs to subtract a phoneme that is at the beginning, middle, or end of the word. There are also three practice items for this part of the subtest. First, the examinee repeats the heard word and then says the word without a phoneme. For instance, the word *meet* without */t/* becomes *me.* For the three practice items and the first two test items, the experimenter gives feedback about the correctness of the response. For the rest of test items, no feedback is provided. If the examinee misses three test items in a row, the experimenter stops the test. During the test, correct answers are scored 1 and 0 is attributed to incorrect answers. The number of correct answers out of 20 test items is the final score of the examinee.

7.4.1.2.2 Memory for digits

The memory for digits subtest measures the ability to repeat sequences of numbers (digits). The examinee receives instructions about the subtest where s/he needs to recall numbers in the same order as they have been previously heard from the CD. The experimenter plays them only once. There are four practice items: two items with two numbers and two items with three numbers. For instance, *5-2* and *6-1-5.* A correct/incorrect feedback is given for practice items, but not for test items. Test items start with two numbers and as long as the examinee progresses in the test, test items increase from two up to nine numbers gradually. Test administration is over when the examinee has missed three test items in a row. The number of correct answers out of 21 test items is calculated at the end.

7.4.1.2.3 Non-word repetition

The non-word repetition subtest measures the ability to repeat non-words accurately. For instance, the examinee needs to repeat a non-word like *ral* /ræl/. Non-words are played from the CD only once. First, the examinee practices with three sample items and receives feedback about the correctness of the response. Then, the examinee is tested on 18 items, where only the first three items are accompanied by feedback. The length of non-words increases progressively where last test items contain up to seven syllables. Testing stops when the examinee has missed three test items in a row.

7.4.1.2.4 Rapid letter naming

The rapid letter naming subtest measures the ability to name letters as quickly as possible. This subtest includes a practice session and two forms (A and B). Each form contains four rows of nine letters each. For this subtest, the experimenter needs a stopwatch in order to record the number of seconds that the examinee takes to name all the letters of both forms. The total score is the sum of time for Form A and Form B. If the examinee makes errors while naming letters, the experimenter keeps record of those in a special printed form. In addition, when the examinee makes more than four errors in Form A, s/he does not perform on Form B.

7.4.1.2.5 Phoneme reversal

The phoneme reversal subtest measures the ability to reverse the order of speech sounds to form a word. The examinee listens to a CD recorded series of non-words. First, the experimenter plays practice items, pausing after each one. There are four practice items and three test items accompanied by a correct/incorrect feedback. After playing the non-word, the examinee is asked to repeat it immediately to make sure s/he has heard it correctly and then say the real word. For instance, upon hearing /nʌs/, the examinee repeats this non-word and then says it backwards as the word *sun*. If the examinee repeats the non-word incorrectly, the non-word is played again and up to three times until the examinee gets its pronunciation. If the pronunciation is still incorrect or if the response is not correct, the item is scored 0, and the experimenter proceeds with the next test item. Testing stops when three test items have been missed in a row. In total, there are 18 test items.

7.4.1.3 Test of Word Reading Efficiency – Second Edition (TOWRE-2)

The Test of Word Reading Efficiency – Second Edition (TOWRE-2) measures the ability to pronounce printed words and non-words accurately and fluently. The TOWRE-2 consists of two subtests. In the first subtest, Sight Word Efficiency (SWE), the examinee has 45 seconds to read words like *dog* or *threshold* organized in vertical lists. The total number of stimuli is 108. The number of accurately pronounced words corresponds to the final score. In the second subtest, Phonemic Decoding Efficiency (PDE), the examinee needs to decode phonetically regular non-words like *nade* or *strilmolifant* presented in vertical lists. The total number of stimuli is 66. The experimenter keeps records of the number of non-words accurately pronounced within 45 seconds for scoring. Both subtests are of comparable progressive difficulty as they start with two-letter stimuli and continue with multi-letter stimuli. Besides being relatively fast in administration (about 5 minutes, including time for instructions and practice items), the TOWRE-2 provides an efficient means to monitor fluency and accuracy of word reading skills.

7.4.1.4 Test of Irregular Word Reading Efficiency (TIWRE)

The Test of Irregular Word Reading Efficiency (TIWRE) measures the ability to pronounce phonetically irregular words. The test starts with letters where the examinee needs to say each letter aloud: six capital and five lower case letters. Then, letters are followed by irregular words, which vary in length from one to four syllables. This test is not time limited. However, the administration ceases once the participant pronounces three words incorrectly. The total number of stimuli is 50 and the examinee is attributed the score which corresponds to the number of correctly pronounced stimuli.

7.4.1.5 Wechsler Adult Intelligence Scale (WAIS-IV)

The Wechsler Adult Intelligence Scale – fourth UK edition (WAIS-IV) is a selection of subtests that measure intelligence in adults from 16 to 90 years old. The WAIS-IV has four main scales: verbal comprehension, perceptual reasoning, working memory and processing speed (Sattler & Ryan, 2009). Each scale contains core and supplement subtests. In total, there are 15 subtests. Due to time constraints, only core subtests of perceptual reasoning and processing speed were used. These were block design, matrix reasoning, visual puzzles, symbol search and coding. The description of these subtests is presented next.

7.4.1.5.1 Block Design

The block design subtest is a core subtest of perceptual reasoning scale. It measures spatial and manipulative abilities of the individual. For its administration, the experimenter uses 9 six-sided plastic blocks (cubes). Each block has two sides with white surface, two sides with red surface, and two sides with surfaces painted diagonally half-white and half-red. The experimenter shuffles all the blocks and explains that the examinee needs to recreate the design shown on a computer screen. For the first four items, the examinee observes the experimenter reproducing designs, using two blocks for items 1 and 2, and four blocks for items 3 and 4. Depending on the design, two, four or nine blocks are required. After the completion of each design, the experimenter shuffles the blocks again and asks the examinee to recreate designs again. Afterwards, the examinee only sees test items with designs on the computer screen and reproduces them alone. In total, there are 14 test items. Besides the design becoming more complex, the examinee needs to manipulate more blocks, for example, nine blocks to reproduce designs for items 11 to 14 (see Figure 7.1). Each test item has its proper score value, which is also influenced by the time the examinee took to complete the design. For instance, items 1 to 4 must be completed in 30 seconds, but items 11 to 14 have the time limit of 120 seconds. If the examinee fails to reproduce a design successfully within the specified time limit, some score points are deducted. Therefore, the final score of this subtest represents both speed and accuracy of the examinee's performance.

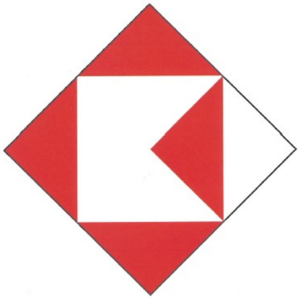

Figure 7.1. An example of a block design item.

7.4.1.5.2 Matrix Reasoning

The matrix reasoning subtest is also a core subtest of perceptual reasoning scale. This subtests measure simultaneous processing and perceptual organization of the individual. In this subtest, the examinee is required to choose one part from a series of five options, which logically completes the matrix. Matrices consist of different shapes and colours (see Figure 7.2). There are two sample items and 26 test items, which are presented on the computer screen The experimenter provides feedback only of the two sample items. Performance is not time limited, but if the examinee does not respond within 30 seconds, the experimenter asks to point to the response option or say the number of the response. Correct responses are scored 1 and incorrect responses are scored 0. The maximum total raw score for this subtest is 26.

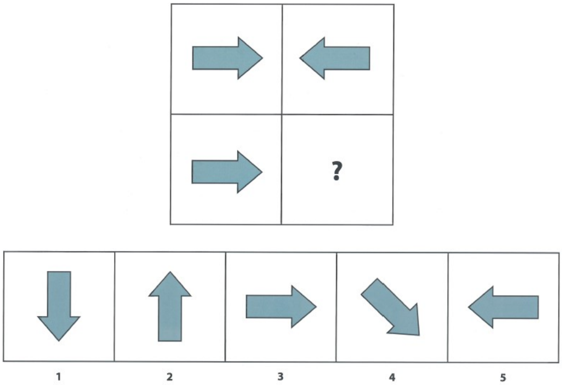

Figure 7.2. An example of a matrix reasoning item.

7.4.1.5.3 Visual Puzzles

The visual puzzles subtest is a new core subtest of perceptual reasoning scale. It measures the ability to analyse and synthesize visual information. The examinee sees a puzzle on a computer screen, which s/he needs to analyse by breaking it down into three pieces. Afterwards, the examinee needs to search for the three pieces from a list of six that go together to reconstruct that puzzle (see Figure 7.3). These pieces may also be spatially rotated, so the examinee needs to rotate them figuratively in order to check whether they match the puzzle. The subtest consists of one demonstration item, one sample item, and 26 test items. In addition, the experimenter uses a stopwatch to control the time required to execute each test item. Time limits are different for each test item due to the complexity. This way, items 1 to 7 have the limit of 20 seconds, and the time limit for items 8 to 26 is 30 seconds. The experimenter stops timing once the correct response is given. Regarding the scoring, the experimenter attributes 0 when the response is incorrect or when the response is not given within the specified time limit. If the correct response is provided within the time limit, the test item is scored 1. The total maximum score is 26.

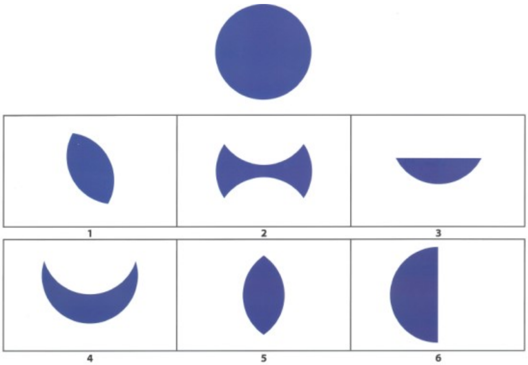

Figure 7.3. An example of a visual puzzles item.

7.4.1.5.4 Symbol Search

The symbol search subtest is a core subtest of the processing speed scale. It measures the ability to discriminate visual information quickly and correctly. This subtest is administered in a paper booklet and requires the examinee to inspect the two target symbols in the grey area and decide whether either of the target symbols is present in a row of various symbols (the search group). In some cases, there is no target symbol in the corresponding row. Once the decision is made, the examinee needs to mark the appropriate symbol or the NO box, respectively (see Figure 7.4). The majority of these symbols do not have a meaning, i.e., it is difficult to encode them verbally, with exception of few symbols like > (greater than) or ± (plus or minus). There are three demonstration items and three sample items for practice, which are not time limited. Once the examinee understands the procedures, s/he receives the test booklet. The subtest contains 60 test items and the examinee has 120 seconds to complete the subtest. If the examinee does not finish within the time limit, s/he is stopped by the experimenter and cannot proceed with the subtest. The number of correctly marked symbols is the total score of the subtest.

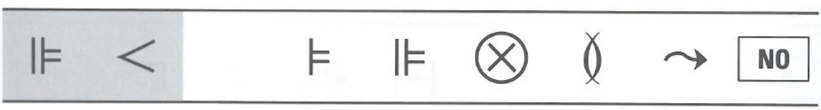

Figure 7.4. An example of a symbol search item.

7.4.1.5.5 Coding

The coding subtest is also a core subtest of the processing speed scale. It measures the ability to process visual information and make associations quickly and accurately. The examinees receives a paper booklet accompanied by the key that pairs numbers from 1 to 9 with the symbols at the top of the page (see Figure 7.5). The objective of the examinee is to code each number based on its corresponding symbol. The response booklet consists of boxes with a number in the upper part and an empty space underneath the number. In the subtest, there are three demonstration items, 6 sample items, and 135 test items. The performance on the sample items is not timed, but for the test items, the examinee has 120 seconds. The examinee cannot exceed this time limit. The number of correctly coded numbers within the time limit is the total score of the subtest.

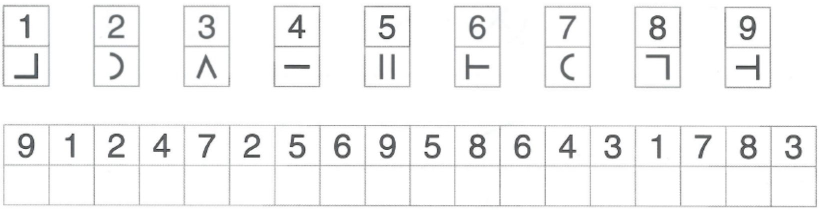

Figure 7.5. An example of a coding item.

7.4.1.6 Corsi Block-Tapping Task

The Corsi block-tapping task measures visuo-spatial short-term working memory. Traditionally, the task is administered with the use of nine cubes placed on a wooden board and the experimenter taps the cubes in sequences starting with two. If the examinee reproduces the sequence correctly, the sequence length increases by one cube. Today, the digital version of this task is available for administration. The examinee sits in front of the computer screen and sees nine blue squares on a black background. The squares lit up yellow one at a time in a certain sequence (see Figure 7.6). For each trial, the squares appear in different spatial positions across the screen. The examinee needs to remember this sequence and then click on each square in the same order as the squares have been previously lit up. Once it is concluded, the examinee clicks the button labelled *done* and proceeds to the next trial. The examinee starts the task with a sequence of two squares. When the examinee gets the first trial correctly, the sequence of the next trial increases by one. The sequence becomes more complex until the examinee's performance suffers. If the examinee does not remember the sequence, s/he is instructed to click on the squares in the sequence, which closely resembles the original one. If the examinee makes a mistake, s/he has one more chance as there are two trials for each sequence length. For each item, there appears feedback regarding the correctness of the response on the computer screen. The examinee's score, which is known as the Corsi span, corresponds to the longest sequence of squares that has been reproduced correctly at least once. The average Corsi span for a healthy individual is between 5 and 7 (Kessels, Zandvoort, Postma, Kappelle, & Haan, 2000).

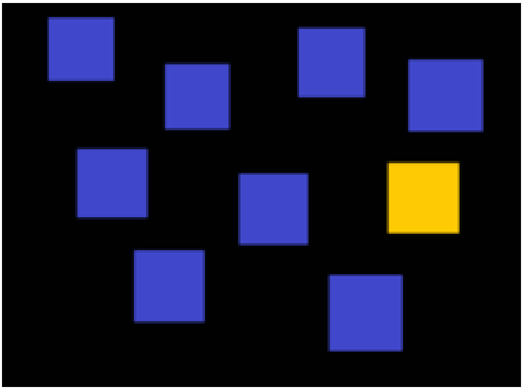

Figure 7.6. An example of a Corsi block-tapping item.

7.4.2 The experimental task

The experimental task employed a syntactic priming paradigm where active and passive sentences were primed several times. In total, the task had 297 sentences. Out of these, 150 were passive sentences with the *patient - auxiliary verb - main verb – by - agent* structure, for example, *The bill was paid by the client*. The passive structure was the focus of investigation in Study III. In addition to passive sentences, there were 147 filler sentences, which were included to avoid participants guessing the objective of investigation. Filler sentences were split into 77 active sentences with the *agent – verb - patient* structure, for example, *The children bought the lunch*, and 70 active sentences with the *agent – verb – complement* structure, for example, *The dog sat very still.* The full list of sentences is presented in Appendix E3.

Passives were presented in mini-blocks of five sentences. All sentences within a mini-block shared the same verb, for instance, the verb *paid* would be repeated across all five sentences. Lexical repetition at the verb was also maintained for filler sentences, which were organized in mini-blocks with the number of sentences varying from three to seven. Taken together, prime and target sentences within a mini-block shared not only the syntactic structure, but also the same verb. No other content words were repeated within a mini-block. In total, the task consisted of sixty mini-blocks, alternating between thirty mini-blocks of passive sentences and thirty mini-blocks of filler sentences.

The presentation of the stimuli had a similar design as in Study I and Study II. Firstly, participants had a practice session in order to get familiar with the procedures. Once they understood the instructions and clarified their doubts, they started the experimental task. Following a fixation cross (1000ms), participants saw the first word of a sentence. By pressing the space bar, participants navigated through the sentences word by word in a serial way. The last word of the sentence ended in a period. Words were presented on a light green background, using black characters (Arial, font size 18). Figure 7.7 depicts the experimental design of a passive sentence presentation.

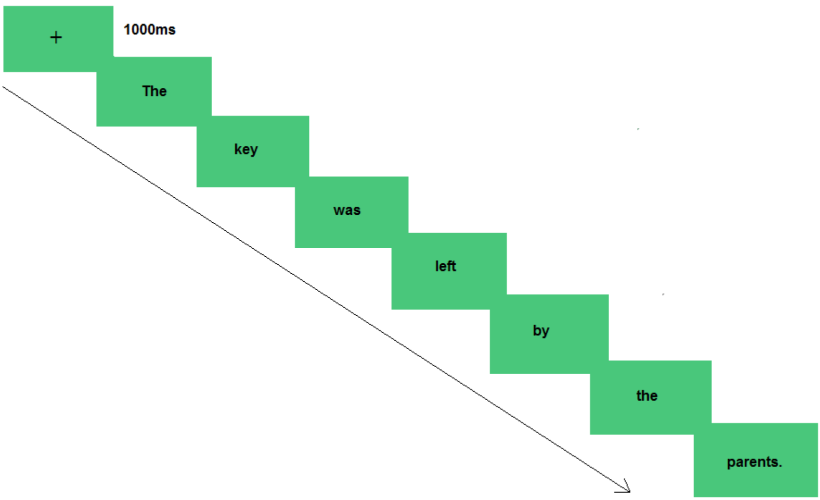

Figure 7.7. Experimental design of a passive sentence presentation (Study III).

It is important to clarify how the experimental sentences and filler sentences were created. Similarly to Experiment 1, the experimental material of this study was based on a lexical database. The database used was the N-Watch program, which is available, free of charge, from the following web site: http://www.maccs.mq.edu.au/~colin/N-Watch/. This program provides a broad range of lexical statistics, including measures of word frequency, length, number of syllables, neighbourhood size, and so on. The default vocabulary for the N-Watch program is a result of cross-checking of the raw CELEX English Corpus Types, or ECT, against an on-line dictionary with 65,013 words where entries with the occurrence fewer than seven times in the entire corpus of 17.9 million words were excluded.[34] Moreover, the default vocabulary does not contain words shorter than two letters or longer than ten letters because words of this length are not typically used in most psycholinguistic experiments. The resulting vocabulary comprises 30,605 words. The words selected from the database were controlled for frequency (between 150 and 600 occurrences per million) in order to ensure that participants would be familiar and reading times would not reflect processing difficulty associated with accessing the meaning. In addition to word frequency, word length was also controlled. This way, the words within one mini-block had the same or similar number of letters for the sake of standardizing reading times for each sentence and ruling out the fact that longer words require more effort and time for processing. For instance, if the agent of the first sentence was a word of four letters (e.g., *wife*), all agents in further sentences of the mini-block would be of the same or similar word length.

The experimental sentences in English were created with the help of two undergraduate students from the University of Birmingham under the supervision of professor Katrien Segaert. All sentences were submitted to an acceptability judgment test. The raters were ten university students, native speakers of English , who, in a voluntary condition, judged whether sentences were both structurally (grammatically) acceptable and meaningful. They received a list of the sentences with instructions for assessment by email (see Appendix C3). Sentences were assessed on a 5-point Likert scale, from not at all acceptable (score value

[34] CELEX is the Dutch Centre for Lexical Information, which was developed as a joint enterprise of the University of Nijmegen, the Institute for Dutch Lexicology in Leiden, the Max Planck Institute for Psycholinguistics in Nijmegen, and the Institute for Perception Research in Eindhoven. Over the years, it has received financial support mainly from the Netherlands Organization for Scientific Research (NWO) and the Dutch Ministry of Science and Education. There are versions for different languages like English, Dutch, and German.

1) to completely acceptable (score value 5). Sentences with a mean score of 4 were selected and used in the experimental task.

To ensure the participants' attention to the experimental stimuli, simple yes-no comprehension questions were included at the end of each mini-block. As the number of sentences varied in mini-blocks of passive and filler sentences, participants hardly could predict the appearance of questions. This way as passive mini-blocks always contained five sentences, a comprehension question always popped up after the fifth sentence. However, in mini-blocks of filler sentences, a comprehension question could appear after the third, fourth, fifth, sixth or seventh sentence, depending on the number of filler sentences within a particular mini-block. Half of the answers to these questions corresponded to *no* and the other half corresponded to *ye*s. Participants used a keyboard where small 'y' and 'n' stickers were placed over the *P* and *Q* keys on the keyboard, respectively. The experimental task was designed by two undergraduate students under my supervision and the supervision of Professor Katrien Segaert from the University of Birmingham.

7.5 RESULTS

This section reports the results of the statistical analyses of the collected data. The section is organized into three subsections. In the first subsection, the results of the analysis of language-based skills, i.e., participants' performance on the GSRT, CTOPP, TOWRE-2 and TIWRE tests, are reported and compared between the experimental and control groups. The second subsection, presents the results of the WAIS-IV subtests and the Corsi task of each group and the analysis for group comparisons. The third subsection accounts for the groups' performance on the experimental task and reports the results. In all subsections, the results are presented in the form of illustrations (line and bar graphs) to facilitate their comprehension.

7.5.1 Language-based skills

The analysis reported in the present subsection aimed at investigating whether the experimental and control groups differ in their language skills, specifically in reading comprehension and phonological awareness. A series of independent samples *t*-tests was performed. The results of each *t*-test are presented according to the chronological order of the subtest execution.

In the first test, the GSRT, the participants read silently 13 passages where each passage was followed by five multiple-choice questions. The total number of questions that the participants answered was 65. Figure 7.8 presented the results of each group performance on this test. On average, the control group experienced more difficulty in answering comprehension questions (*M*=43.29, *SE*=2.47) than the dyslexic group (*M*=52.45, *SE*=1.78). Additionally, the assumption of homogeneity of variances was tested and satisfied via Levene's *F* test, $F(39) = .97$, $p = .332$. The difference of the group means was significant $t(39) = -2.98$, $p = .005$ with a medium-sized effect $r = 0.43$.

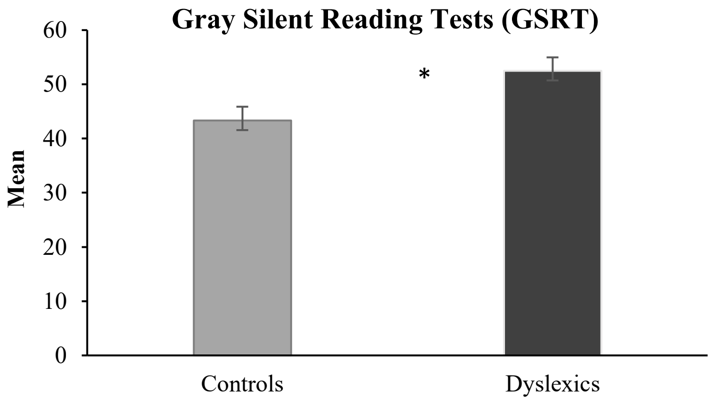

Figure 7.8. Group means for the GSRT (Study III).
Note. Error bars denote one standard error around the mean. An asterisk (*) indicates statistically significant differences between the groups.

In order to assess participants' phonological processing skills, they were required to take five subtests selected from the CTOPP. These subtests were: elision, memory for digits, non-word repetition, rapid letter naming, and phoneme reversal. The responses to these subtests were analyzed and Figure 7.9 displays the results.

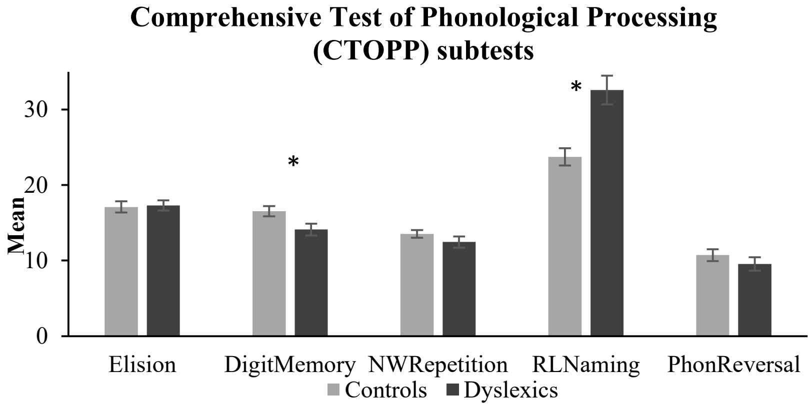

Figure 7.9. Group means for the CTOPP subtests (Study III).
Note. Error bars denote one standard error around the mean. An asterisk (*) indicates statistically significant differences between the groups.

In the elision subtests, the participants produced words without a given phonological segment. The total number of test items was 20, which corresponded to the maximum score for this subtest. On average, both groups performed equally well: the control (*M*=17.10, *SE*=0.74) and the dyslexic group (*M*=17.30, *SE*=0.68). The assumption of homogeneity of variances was tested and satisfied via Levene's *F* test, $F(39) = .47$, $p = .497$. The difference of the group means was not significant $t(39) = -.20$, $p=.840$ with a small-sized effect $r = 0.10$.

The memory for digits subtest measures the ability of the participant to memorize sequences of spoken numbers and reproduce them. The total number of correctly reproduced test items was 21. In this subtests, the control group outperfomed the dyslexic one: (*M*=16.52, *SE*=0.68) and the dyslexic group (*M*=14.10, *SE*=0.77). The assumption of homogeneity of variances was tested and satisfied via Levene's *F* test, $F(39) = 1.94$, $p = .172$. The difference was significant $t(39)= 2.37$, $p=.023$ with a medium-sized effect $r = 0.35$.

In the non-word repetition subtest, the participants had to repeat non-words accurately. The total number of correctly reproduced test items was 18, which corresponded to the maximum score the participants could obtain. The dyslexic group experienced a bit more difficulty to repeat non-words (*M*=12.45, *SE*=0.75) than the control group (*M*=13.52, *SE*=0.52). The assumption of homogeneity of variances was tested and satisfied via Levene's *F* test, $F(39) = 2.66$, $p = .111$. The difference was not significant $t(39) = 1.18$, $p = .243$ with a small-sized effect $r = 0.19$.

The rapid letter-naming subtest assessed the ability of the participants to decode letters aloud as quickly as possible. The participants read two lists of letters and the sum of time of both lists was calculated. The control group took less time to complete the subtest (M=23.72, SE=1.14) in comparison to the dyslexic group (M=32.57, SE=1.90). Additionally, the assumption of homogeneity of variances was tested and did not satisfy via Levene's *F* test, $F(39) = 6.26$, $p = .017$. The difference was significant $t(31.27) = -3.99$, $p < .001$ with a medium-sized effect $r = 0.34$.

In the last CTOPP subtest, phoneme reversal, the participants' ability to reverse the order of speech sounds to form a new word was measured. The total number of correctly produced test items was 18, which was the maximum raw score of the subtest. The control group produced correctly more words (M=10.71, SE=0.80) than the dyslexic group (M=9.55, SE=0.90). Additionally, the assumption of homogeneity of variances was tested and satisfied via Levene's *F* test, $F(39) = .39$, $p = .534$. The difference was not significant $t(39) = 0.97$, $p = .337$ with a small-sized effect $r = 0.15$.

Figure 7.10 reports the results of two word reading efficiency tests. The results of the Test of Word Reading Efficiency – Second Edition (TOWRE-2) reflect the participants' performance on two subtests: Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE), which measured participants' abilities in reading phonetically regular words and non-words, respectively. More specifically, Figure 7.9 displays the means of correctly produced words (out of 108 test items) and non-words (out of 66 test items). Another test, the Test of Irregular Word Reading Efficiency (TIWRE), measured the participants' ability to pronounce phonetically irregular words where the maximum test score that the participants could achieve was 50.

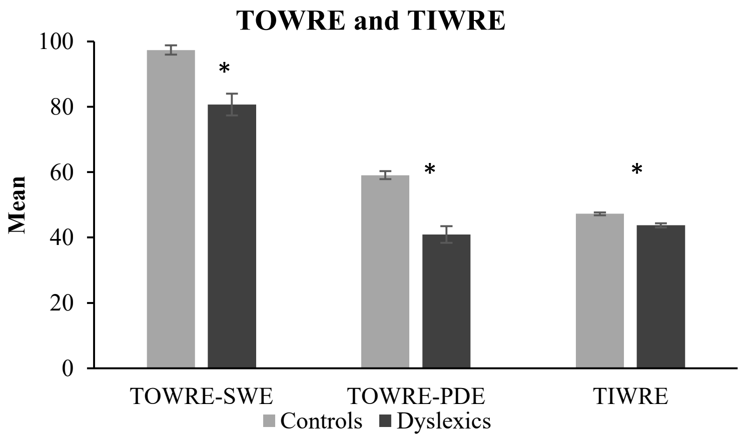

Figure 7.10. Group means for the TOWRE and TIWRE tests (Study III).
Note. Error bars denote one standard error around the mean. An asterisk (*) indicates statistically significant differences between the groups.

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Based on the data for the TOWRE-SWE, the control group read more phonetically regular words (*M*=97.38, *SE*=1.41) in comparison to the dyslexic group (*M*=80.70, *SE*=3.37) within the time limit of the subtest. Moreover, the assumption of homogeneity of variances was not satisfied via Levene's *F* test, $F(39) = 14.51$, $p > .001$. The difference in performance between the groups was significant $t(39) = 4.64$, $p < .001$ with a large-sized effect $r = 0.60$.

The data for the TOWRE-PDE revealed that the control group was also more accurate and faster in reading phonetically regular non-words (*M*=59.10, *SE*=1.27) in comparison to the dyslexic group (*M*=40.95, *SE*=2.57) within the time limit of the subtest. Additionally, the assumption of homogeneity of variances was satisfied via Levene's *F* test, $F(39) = 3.15$, $p = .084$. The difference in performance between the groups was significant $t(39) = 6.43$, $p < .001$ with a large-sized effect $r = 0.72$.

Finally, the TIWRE results demonstrated that the control group was slightly more accurate and faster in reading phonetically regular non-words (*M*=47.29, *SE*=.44) in comparison to the dyslexic group (*M*=43.75, *SE*=.64) within the time limit of the subtest. Additionally, the assumption of homogeneity of variances was satisfied via Levene's *F* test, $F(39) = 1.59$, $p = .216$. The difference in performance between the groups was significant $t(39) = 4.56$, $p < .001$ with a large-sized effect $r = 0.59$.

7.5.2 Wechsler Adult Intelligence Scale – the fourth edition (WAIS-IV) and the Corsi block-tapping task

The present subsection is dedicated to the results of the five subtests of the Wechsler Adult Intelligence Scale – fourth edition (WAIS-IV) and the Corsi block-tapping task, which aimed at assessing intelligence of the participants. Figure 7.11 displays the mean values on the performance for each subtest. Additionally, the data were statistically analyzed using an independent samples *t*-test in order to determine whether the mean differences between two groups were statistically significant. The outcome of this analysis is presented next.

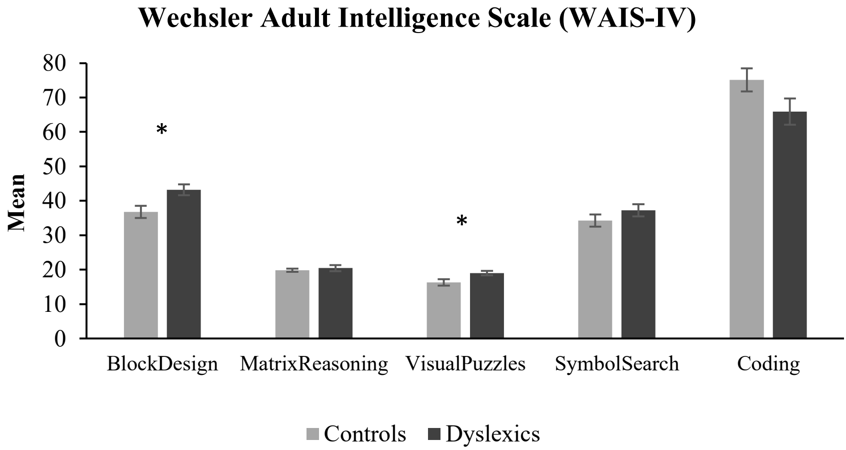

Figure 7.11. Group means for the WAIS-IV subtests (Study III).
Note. Error bars denote one standard error around the mean. An asterisk (*) indicates statistically significant differences between the groups.

The first subtest of the WAIS-IV that the participants completed was block design. In this subtest, their spatial and manipulative abilities were measured. Based on the results, the dyslexics group gained more scores (M=43.20, SE=1.55) in comparison to the control group (M=36.76, SE=1.78). The assumption of homogeneity of variances was tested and satisfied via Levene's F test, $F(39) = 2.10$, p=.156. The difference in performance between the groups was significant $t(39)$= -2.71, p=.010 with a medium-sized effect $r = 0.45$.

In the matrix reasoning subtest, the participants' simultaneous processing and perceptual organization of visual information was assessed. Both groups performed equally well (the control group

M=19.81, *SE*=.47; the dyslexic group *M*=20.45, *SE*=.91). The assumption of homogeneity of variances was not satisfied via Levene's *F* test, $F(39) = 5.12$, p=.029. The difference in performance between the groups was not significant $t(28.52)$= -.63, p=.534 with a medium-sized effect r = 0.45.

The visual puzzles subtest measured the ability of the participants to analyze and synthesize visual information. In this subtest, the dyslexics group gained higher scores (*M*=19.00, *SE*=.63) in comparison to the control group (*M*=16.29, *SE*=.91). The assumption of homogeneity of variances was tested and satisfied via Levene's *F* test, $F(39) = 3.32$, p=.076. The difference in performance between the groups was significant $t(39)$= -2.43, p=.020 with a medium-sized effect $r = 0.41$.

In the symbol search subtest, the participants had to discriminate visual information quickly and correctly. The results showed that the dyslexics group was a bit better in doing this (*M*=37.25, *SE*=1.78) than the control group (*M*=34.25, *SE*=1.79). The assumption of homogeneity of variances was tested and satisfied via Levene's *F* test, $F(38) = .38$, p=.543. The difference in performance between the groups was not significant $t(38)$= -1.19, p=.242 with a small-sized effect $r = 0.19$. [35]

In the last subtest of the WAIS-IV, coding, the participants were measured on their ability to code numbers to their corresponding symbols within the time limit of 120 seconds. The data revealed that the control group was faster and more accurate (*M*=75.10, *SE*=3.37) than the dyslexic group (*M*=65.90, *SE*=3.83). The assumption of homogeneity of variances was satisfied via Levene's *F* test, $F(38) = .57$, p=.453. The difference in performance between the groups was not significant $t(38)$= 1.81, p=.079 with a small-sized effect $r = 0.28$.

The last test that investigated intelligence of the participants was the Corsi block-tapping task. In this task, the participants demonstrated their visuo-spatial short term working memory by reproducing sequences of squares lighting up on the computer screen. Figure 7.12 presents the mean scores of the task, Corsi span, and as can be seen, the scores which were alike in both groups (the control group *M*=5.79, *SE*=.19; the dyslexic group *M*=5.38, *SE*=.20). The assumption of homogeneity of variances was satisfied via Levene's *F* test, $F(39) = .60$, p=.444. The difference in performance between the groups was not significant $t(39)$= 1.49, p=.143 with a small-sized effect $r = 0.23$.

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[35] The data of one participant from the control group was lost for the symbol search and coding subtests. Thus, the analyses of these two tests were based on 20 participants in each group.

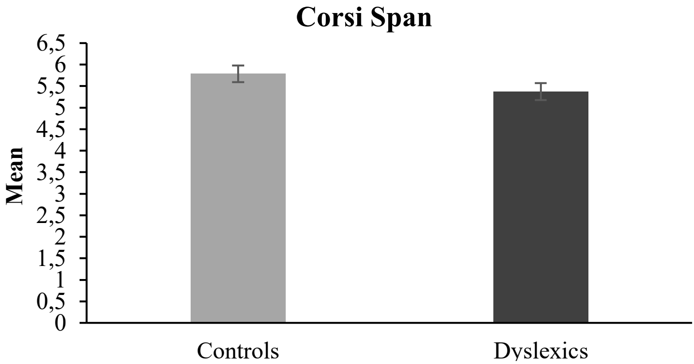

Figure 7.12. Group means for the Corsi block-tapping task (Study III).
Note. Error bars denote one standard error around the mean.

The results presented in the last two sections answer the research questions 1 and 2 about the language skills and IQ of participants and the hypotheses posed for these questions were partially confirmed. The discussion of these results is presented in section 7.6. In the subsequent section, the results on syntactic processing skills are reported, which answer the research questions 3 and 4 about the effects of syntactic priming on sentence processing.

7.5.3 Analyses of the behavioral data

The data of the experimental task retrieved from the E-prime output files were submitted to the following pre-processing steps. First of all, the percentage of correctly answered comprehension questions was checked. No participants were excluded based on poor performance, i.e., low number of hits in comparison to the rest of the group. Then, all reading times (RTs) under 150ms were removed from the data because these values are too fast to represent reading (access to word meaning) and they are likely to be accidental taps on the spacebar (Miller, 2003; Nicenboim, Logačev, Gattei, & Vasishth, 2016). Then, the output of this step was screened for excessively long RTs in relation to the group mean. Based on the means and standard deviations within each group, RTs that were in excess of 2*SD* were removed. The pre-processed data were statistically analyzed based on passive and active conditions.

7.5.3.1 Analyses of passive sentence processing

Figure 7.13 and Figure 7.14 ilustrate the way the control and dyslexic groups processed passive sentences word by word, respectively. The data are based on mean reading times of each word in a sentence within a miniblock.

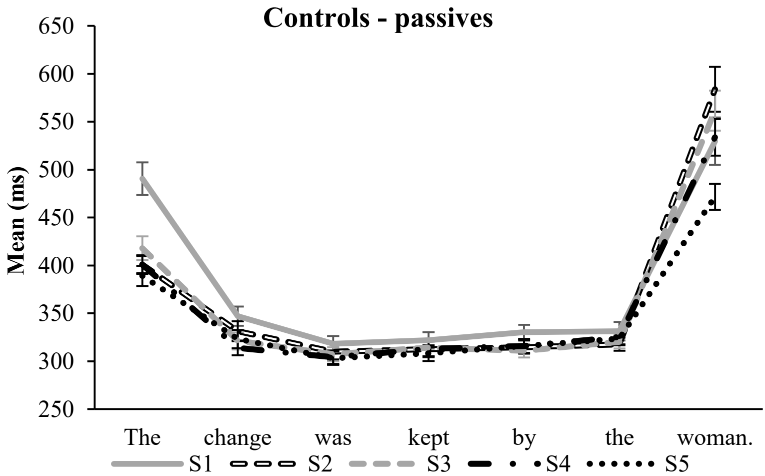

Figure 7.13. Mean reading times for passive sentences in the control group (Study III).

Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the fifth sentence.

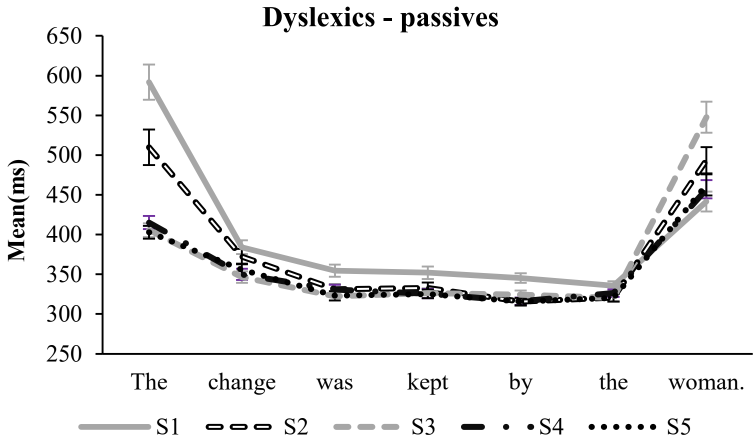

Figure 7.14. Mean reading times for passive sentences in the dyslexic group (Study III).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the fifth sentence.

Inspecting these data, it is possible to observe that the control and dyslexic groups did not differ greatly in their mean reading times, thus demonstrating a very similar reading behavior. When inspecting Figure 7.13 and Figure 7.14 more thoroughly, the following observations can be made. The control group seemed to process all passive sentences within a mini-block similarly with no evident syntactic priming effects. There is a probable decrease in processing the first word (article *The*) after sentence 1. Of interest is the fact that this decrease is also present in the dyslexic group. Additionally, the dyslexic group also demonstrated a decrease in reading times for the first word between sentence 2 and sentence 3. It is worth remembering that the definite article was always repetead across all sentences within all mini-blocks.

Another descrease in reading times of the control group was observed for the last word in sentence 5 in contrast to the pervious sentences of a mini-block. In the dyslexic group, the decrease of reading times for the last word was between sentences 1 and 2. These two cases did not invoke a particular interest as they cannot be explained in terms of syntactic priming effects, but rather some other factors influencing processing.

Conversely, it is possible to see a sign of syntactic priming effects for the auxiliary verb, the participle and the by-preposition in the dyslexic group. As these three words are responsible for the complexity of the passive voice structure, the so called critical region of the passive voice, they were subject to further analysis, which could reveal processing differences between the groups.

The data for the critical region were analyzed by using the repeated-measures ANOVA (rANOVA), with two groups (independent variable: dyslexics and controls) as a between-subject factor and sentence repetition (dependent variable: reading times of the verb over the successive presentation) as a within-subject factor. In the first rANOVA, group was used as a between subject factor in order to see whether there was a statistically significant effect of sentence repetition and whether there was a statistically significant interaction of sentence repetition and group. The second rANOVA was run for each group independently in order to see where exactly a significant difference was, i.e., in which pairwise comparisons of sentences.

Figure 7.15 presents the mean values for the critical region in each passive sentence. Looking at this figure, it is possible to compare how the two groups differed in their processing of the critical region within a mini-block of passives. As expected, the control group processed the critical region faster than the dyslexic group. Moreover, for the control group, there seemed to be a decrease of RTs between sentence 1 and sentence 2, but no further apparent decrease across other sentences. As regards the dyslexic group, similar observations are possible to make. However, the decrease between sentence 1 and sentence 2 appears to be more distinct.

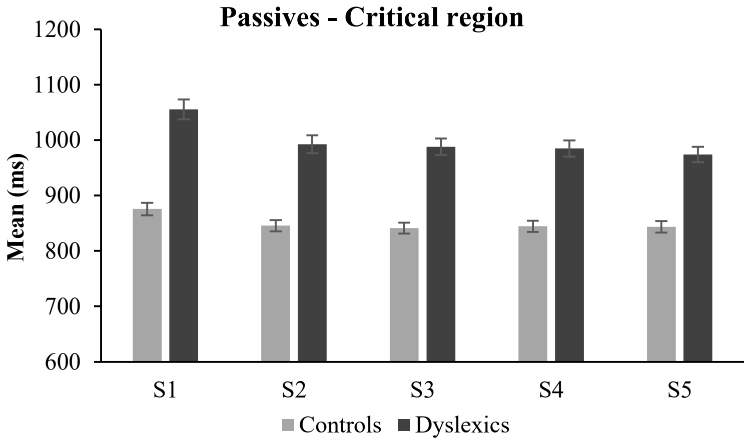

Figure 7.15. Mean reading times for the critical region of passive sentences (Study III).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the fifth sentence.

Mauchly`s test indicated that the assumption of sphericity was violated, $\chi 2$ (9)=51.45, $p<.05$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .60$). The results showed a significant main effect for sentence repetition, $F(2.40, 93.50)=20.32$, p<.001, but not for a group by sentence repetition interaction, $F(2.40, 93.50)= 2.02$, $p=.130$). The Bonferoni post-hoc test suggested a significant difference in means between sentence 1 and the remaining four repetitions ($p<.001$), but no other comparisons with significant values ($p>.05$). The follow-up rANOVA for each group revealed the following results. There was a significant main effect for sentence repetition: the control group, $F(2.55, 50.97)= 6.87$, $p =.001$ with the Greenhouse-Geisser correction ($\varepsilon=.64$); the dyslexic group, $F(2.02, 38.34)= 13.29$, $p <.001$ with the Greenhouse-Geisser correction ($\varepsilon=.50$). The analysis of the Bonferoni post-hoc test revealed a difference approaching significance between sentence 1 and sentence 2 ($p=0.53$) for the control group. In addition, there was a significant difference in means between sentence 1 and sentence 3 ($p= .003$) and sentence 4 ($p=.027$), but not significant difference between sentence 1 and sentence 5 ($p=.061$). Moreover, no other significant values were found for other pairwise comparisons ($p >.05$). With regard to the dyslexic group, the results revealed a significant difference in means between sentence 1 and all four sentence repetitions ($p \leq .01$), but no other statistically significant differences.

Having found some significant priming effects for the critical region in both groups, a decision was taken to analyze whether these effects were more related to a specific word of the region, i.e., the auxiliary verb (word 3), the participle (word 4) and the by-preposition (word 5) since, as can be seen in Figure 7.13, there seems to be a decrease in reading times across the whole region. Thus, these words were submitted to the rANOVA separately.

Figure 7.16 shows the mean RTs for the auxiliary verb *to be* in the 3rd person singular in the past tense (word 3). Comparing the means between the groups, it can be observed that dyslexics were much slower in processing this word across all sentences of a mini-block. The overall difference was about 100ms. Inspecting the mean differences within the group, there seems to be a decrease between sentence 1 and sentence 3 for dyslexics. However, there is no evident decrease for the control group in the processing of word 3.

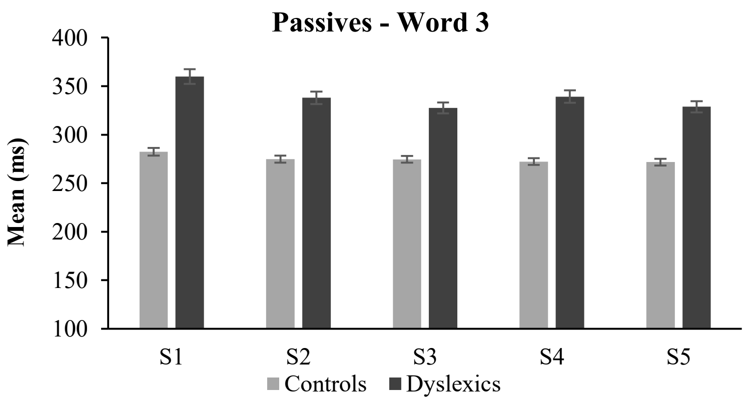

Figure 7.16. Mean reading times for word 3 of passive sentences (Study III).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the fifth sentence.

Mauchly`s test indicated that the assumption of sphericity was also violated, $\chi2$ (9)= 19.49, $p<.05$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .78$). The results of the rANOVA revealed a significant main effect for sentence repetition, $F(3.11,121.23)=12.45$, $p<.001$, and a group by sentence repetition interaction, $F(3.11,121.23)=3.94$, $p=.009$. The Bonferoni post-hoc test suggested a significant difference in means between sentence 1 and all four repetitions ($p<.011$), but no other comparisons with significant values ($p>.05$). The follow-up rANOVA for each group suggested that there was a significant main effect for sentence repetition: the control group, $F(4,80)= 2.57$, $p=.044$ with sphericity assumed; the dyslexic group, $F(2.55, 48.40)= 10.50$, $p<.001$ with the Greenhouse-Geisser correction ($\varepsilon = .64$). The Bonferoni post-hoc test indicated a significant difference in means of the dyslexic group between sentence 1 and sentence 2 ($p=.001$), sentence 1 and sentence 3 ($p<.001$), and sentence 1 and sentence 5 ($p=.002$), but not between sentence 1 and sentence 4 ($p=.095$), and between any other comparisons. As expected, the control group did not present any significant difference between group means ($p>.05$).

With regard to word 4, Figure 7.17 demonstrates similar RT mean difference between the groups. Interestingly, the decrease in RT means seems to be continuous across all sentences in the dyslexic group, whereas the control group is likely to have a little decrease in RT means between sentence 1 and sentence 2, and sentence 4 and sentence 5.

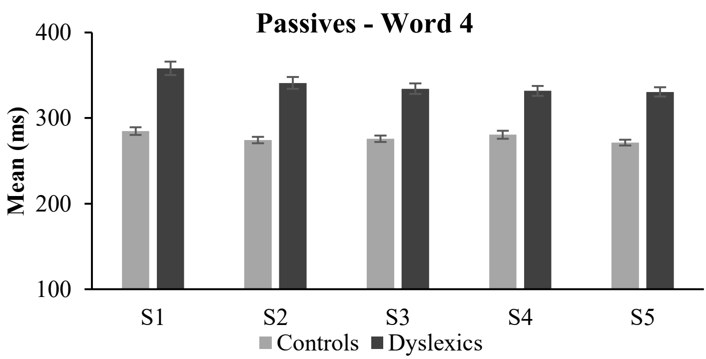

Figure 7.17. Mean reading times for word 4 of passive sentences (Study III). *Note.* Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the fifth sentence.

Mauchly`s test indicated that the assumption of sphericity was also violated, $\chi2$ (9)= 54.62, $p<.01$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .59$). The results of the rANOVA revealed a significant main effect for sentence repetition, $F(2.37, 1\ 92.41)=7.10$, $p=.001$, but no significant main effect for a group by sentence repetition interaction, $F\ (2.37, 1\ 92.41)=1.59$, $p=.206$. The Bonferoni post-hoc test indicated a significant difference between sentence 1 and all four repetitions ($p<.05$), but not other comparisons with significant values ($p>.05$). The follow-up rANOVA for each group showed that there was a significant main effect for sentence repetition: the control group, $F(4,80)= 2.91$, $p =.026$ with sphericity assumed; the dyslexic group, $F(1.87, 35.56)= 4.83$, $p=.016$ with the Greenhouse-Geisser correction ($\varepsilon = .47$). However, the Bonferoni post-hoc tests indicated no significant difference in sentence repetition comparisons for both groups ($p>.05$). The only comparison between sentences that approximated a significant value was between sentence 1 and sentence 4 in the dyslexic group ($p=.057$).

Mean reading times for the final word of the critical region, the preposition by (word 3), are shown for each group in Figure 7.18. Comparing the means of the groups, it is possible to see that dyslexics were again slower in processing this word across all sentences of a mini-block. The mean RT for sentence 1 was the longest and for sentence 5 was the shortest. With regard to the mean differences of the control group, the longest RT mean was for sentence 1 and the shortest one was for sentence 3. In addition, it is possible to observe a more pronounced decrease between sentence 1 and sentence 2 in the dyslexic group, whereas no obvious decrease in the control group.

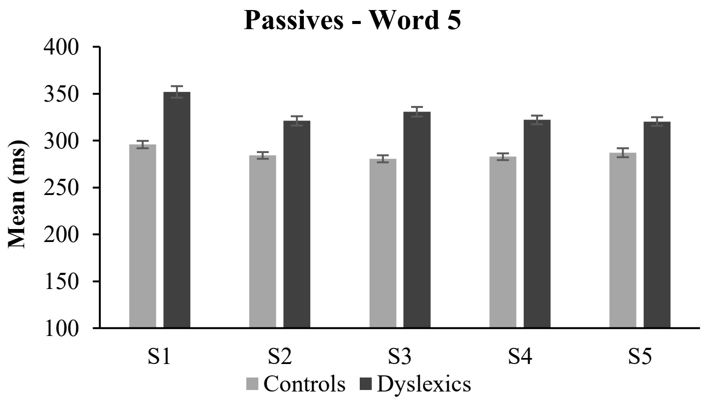

Figure 7.18. Mean reading times for word 5 of passive sentences (Study III).

Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, and S5 – the fifth sentence.

Mauchly`s test indicated that the assumption of sphericity was also violated, $\chi2$ (9)= 40.41, *p*<.001, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .66). The results of the rANOVA revealed a significant main effect for sentence repetition, *F*(2.62,102.28)= 18.70, *p*<.001 and for a group by sentence repetition interaction, *F*(2.62,102.28)= 3.86, *p*=.015. The Bonferoni post-hoc test indicated a significant difference between sentence 1 and all four repetitions (*p*<.001), but there were no other comparisons with significant values (*p*>.05). The follow-up rANOVA for each group showed that there was a significant main effect for sentence repetition for both groups: the control group, *F(*2.50, 50.05)= 4.60, *p* =.010 with with the Greenhouse-Geisser correction (ε = .63); the dyslexic group, *F(*2.10, 39.88)= 16.76, *p*<.001 with the Greenhouse-Geisser correction (ε=.53). The Bonferoni post-hoc tests indicated a statistically significant difference between sentence 1 and sentence 2 (*p*=.006), sentence 1 and sentence 3 (*p*=.004) for the control group. With regard to the dyslexic group, there was a statistically significant difference between sentence 1 and all four repetitions (*p*<.05).

7.5.3.2 Analyses of active sentence processing

Although the main objective of the present dissertation and of Study III is to investigate syntactic priming effects for passives, it is also important to look at actives, the alternative structure, as a form of control analysis to see whether some syntactic priming effects are present there as well. Following Ferreira and Bock (2006), syntactic priming effects for active sentence are small or non-existent. It is worth remembering that in the experimental task, active sentences followed the same criteria as passive sentences in that the syntactic structure as well as the verb within mini-blocks were repeated. Figure 7.19 and Figure 7.20 show mean RTs for each word of the sentence for the control and dyslexic group, respectively.

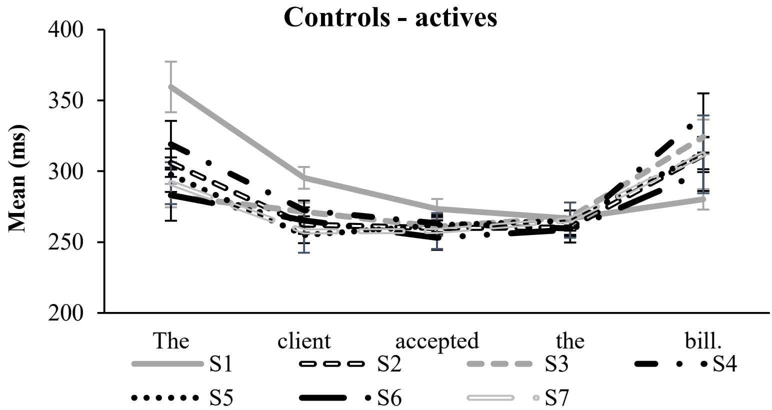

Figure 7.19. Mean reading times for active sentences in the control group (Study III).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, S5 – the fifth sentence, S6 – the sixth sentence, and S7- the seventh sentence.

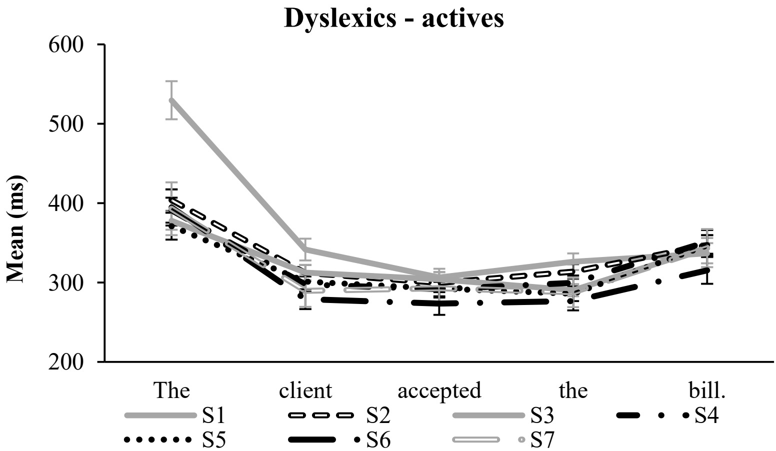

Figure 7.20. Mean reading times for active sentences in the dyslexic group (Study III).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, S5 – the fifth sentence, S6 – the sixth sentence, and S7- the seventh sentence.

Comparing reading behavior for active sentences, it is possible to state that the groups were quite similar. The two groups processed the first two words of sentence 1 in the same way where means of RTs were much longer for sentence 1 than for other six sentences. No other mean differences were evident. Looking more specifically for the verb, word 3, which was repeated across all sentences, no clear effects of syntactic priming were observed (Figure 7.20). In order to find statistical support to this observation, the rANOVA was carried out for the verb repetition.

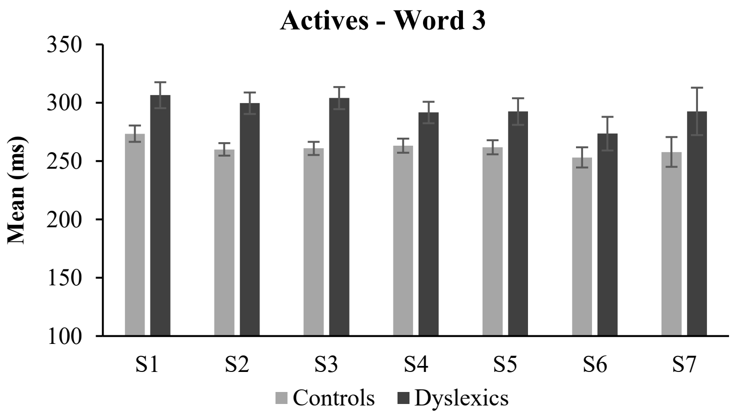

Figure 7.21. Mean reading times for word 3 of active sentences (Study III).
Note. Error bars denote one standard error around the mean. S1 corresponds to the first sentence of a mini-block, S2 – the second sentence, S3 – the third sentence, S4 – the fourth sentence, S5 – the fifth sentence, S6 – the sixth sentence, and S7- the seventh sentence.

Mauchly`s test indicated that the assumption of sphericity was also violated, $\chi 2$ (20) = 35.33, $p<.05$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .49$). The results of an rANOVA indicated a significant main effect for sentence repetition, $F(2.94,46.97)= 2.94$, $p=.044$, but not for a group by sentence repetition interaction, $F(2.94,46.97)= .87$, $p=.522$. The Bonferoni post-hoc test showed a significant difference between sentence 1 and sentence 6 ($p=.031$), sentence 3 and sentence 6 ($p=.028$), but there were no other comparisons with significant values ($p>.05$). In order to see which group had a significant effect of repetition, the rANOVA was carried out for each group. The results showed that there was a significant main effect for sentence repetition in the control group, $F(6, 36)= 2.88$, $p=.021$ with the sphericity assumed, but not for the dyslexic group, $F(6,60)= 1.44$,

p=.215 with the sphericity assumed. Inspecting the Bonferoni post-hoc tests for the control group, the only significant value was for the comparison between sentence 3 and sentence 6 (p=.017). As expected, no significant values for the comparisons in the dyslexic group (p>.05).

7.6 DISCUSSION

The present section aims at discussing the results reported in the previous section in light of the literature and the hypothesis proposed for this study. The discussion is organized according to the three general assessments that were carried out for each participant as well as the research questions and hypotheses related to these assessments: language-based skills, intelligence, and syntactic priming effects. First, the results concerning the assessment of language-based skills are discussed in terms of the predictions made for each group. Afterwards, I discuss the results of the intelligence assessments for each group. Finally, yet importantly, I address the impact of syntactic priming when high-achieving dyslexic adults process passive and active sentences.

The language-based skills of the participants were measured with the use of the GSRT, CTOPP, TOWRE, and TIWRE. The GSRT assessed comprehension ability by reading silently short passages ordered by increasing difficulty. Unexpectedly, the dyslexic group outperformed the control group where the difference between the groups was significant. These findings are not in line with Hypothesis 1, in which I predicted the opposite outcome. One possible explanation for these unexpected results comes from a parsimonious analysis of the control group data. Here, there are four participants that scored below 50% of the test and the group range of scores was quite high (41 scores), whereas no dyslexics scored so poorly and the group range of scores was smaller (26 scores). Such low performance of these control participants skewed the average group score considerably. These observations suggest that some participants from the control group performed the task without paying full attention. Lack of full attention can be due to many factors that could not be controlled by the experimenters, such as anxiety, being preoccupied, depression, or even poor effort. On the contrary, good performance of the dyslexic group can be explained by the fact that all participants were university students and were used to deal with much reading and interpretation of texts. As the GSRT did not impose time limits, i.e., reading fluency was not taken into account, dyslexics felt more comfortable with the reading activity so that their comprehension was not affected.

Based on the CTOPP assessments, the comparisons between the groups did not reveal such clear insights. It was expected that dyslexics would be considerably worse than the control group, especially on the tasks that involved phonological processing abilities. By contrast, dyslexics and controls did not differ greatly from each other. The peculiarity of the dyslexics' high performance is that they appeared to take longer time on the CTOPP tasks. In the two tasks, Elision and Phoneme reversal, in which participants were required to manipulate phonemes, both groups performed equally well. In addition, in the non-word repetition task, there were also no significant differences between controls and dyslexics. These findings also reject Hypothesis 1 posed in section 7.1. It seems that the reading difficulty of dyslexics cannot be solely attributed to the phonological processing deficit because dyslexics were able to compensate their phonological difficulties by applying some developed strategies and performed equally well as controls.

Moreover, there were two tasks, which measured the phonological short-term memory capacity of the participants. In the classic memory span task, memory for digits, participants needed to repeat sequences of numbers. In the tested sample, the control group outperformed the dyslexic group. However, in the task where participant needed to repeat non-words, the scores of the dyslexic group did not differ greatly from the scores of the control group. Baddeley, Gathercole and Papagno (1998) suggest a strong relationship between lexical knowledge and non-word repetition, where a non-word repetition ability is a predictor of vocabulary acquisition. In a similar vein, Comblain (1999) claims that individuals rely more on their lexical knowledge in order to facilitate information recall when dealing with digits and words rather than non-words. In light of the above and based on the results of the memory for digits task, it may be suggested that dyslexics' lexical knowledge is a bit limited. Although the results of the groups did not differ significantly for the non-word repetition task, on average the dyslexics performed a bit worse than the control group. This evidence also provides some support to a more limited lexical knowledge of dyslexics.

In the last task of the CTOPP assessments, rapid letter naming, the control group outperformed the dyslexic one. These results were expected because following the double-deficit hypothesis proposed by Wolf and Bowers (2000), dyslexics have a deficit in naming speed. According to the researchers, this is a second core deficit of dyslexia, with the main core deficit being the well-established phonological deficit (Wolf & Bowers, 2000). Rapid naming is essential for fluent word identification and it is to a great extent independent of general phonological processing skills. For the high-achieving sample of dyslexics that participated in the assessment, it is assumed that letter identification is overlearned and automatized. In this ambit, it is reasonable to think that being relatively less efficient in this task reflects their slow global processing speed (Catts, Gillispie, Leonard, Kail, & Miller, 2002).

In order to advance further understanding of the dyslexics' ability to identify linguistic orthographic material, the TOWRE and TIWRE were administered. In the former assessment, participants read lists of phonetically regular words and non-words. In the latter assessment, participants read phonetically irregular words. On both lists, the dyslexic group was significantly weaker than the control group. Although the administration of both lists was time limited, dyslexics performed worse when reading non-words than when reading words. Following Coltheart (2005), it is expected that dyslexics demonstrate more problems in reading non-words as these novel words are not present in their mental lexicon. Put another way, non-words cannot activate corresponding lexical entries because they are not there. In addition, having poor phonetic rules, dyslexics cannot use them to decode non-words. On the contrary, typically developing children make use of these rules to decode non-words. Furthermore, in the latter assessment, the TIWRE, participants needed to read phonetically irregular words. The performance of the TIWRE was not limited to time, but it was limited to the three words pronounced incorrectly in a sequence. Despite the fact that dyslexics also performed more poorly than controls, no dyslexics scored below 70%. These results indicate that these irregular words were present in their lexicon, thus generating less difficulty in identification.

Taken together, the results of the language-based assessment reveal that the dyslexic group experienced difficulties in phonological processing and representation, which inevitably affected their performance on the abovementioned tasks. Despite having improved their reading abilities evidenced by the fact that all were university students, the dyslexic participants performed significantly less well on the majority of language-based tasks than the control participants. In this realm, it is possible to conclude that the phonological processing deficit persisted in this dyslexic sample over time when compared to the control group matched on age and education. This overall conclusion about language-based skills answers the first research questions (RQ1) and partially confirms Hypothesis 1 regarding dyslexics` difficulties with language processing.

Traditionally, the diagnosis of dyslexia is based on underachievement in reading for chronological age, which is not associated with low intelligence (Shaywitz & Shaywitz, 2005). In support of this contention, there is sufficient evidence from dyslexics with average or above average intellectual capabilities (Das, Mishra, & Kirby, 1994; Nopola-Hemmi et al., 2001). Therefore, discrepancy between intelligence and reading development is taken into consideration when discriminating dyslexics from poor readers with low IQ that seem to exhibit similar difficulties in phonological processing (Kuppen & Goswami, 2016). However, it is possible that someone with low intelligence is also diagnosed with dyslexia (Hornsby, 2011). Not surprisingly, recently the discrepancy model has been questioned. Researchers doubt about the utility of intelligence tests, which measure high-level intellectual skills not associated with learning to decode printed material (Fisher & DeFries, 2002; Gus & Samuelsson, 1999; Stuebing et al., 2002; Vellutino et al., 2004).

In the present study, owing to the belief that the hallmark of dyslexia is a discrepancy between reading and general intelligence, participants were assessed by six non-verbal cognitive tasks. The results of the four tests, in which participants dealt with various visual symbols, showed that the groups did not differ in performance. In the other two tests, in which participants had to manipulate visual information in order to solve puzzles, the dyslexic group outperformed the control group. These findings answer the second research question (RQ 2) and are in line with Hypothesis 2 that predicts intact general intelligence and reasoning of dyslexics.

There are strong grounds, though, for supposing that other levels of language such as morphology, semantics and syntax are also affected in dyslexia (Bishop & Snowling, 2004; Joanisse, 2004; Rispens, 2004). In the experimental task, syntactic processing of dyslexics was investigated using the syntactic priming paradigm as a tool (Bock, 1986; Branigan et al., 1995). It was expected to see facilitatory effects of priming in the form of decreased response latencies between the prime and the target for both groups, with especially stronger effects for the dyslexic group.

Indeed, there was a significant difference in the way the two groups processed sentences. As expected, the dyslexic group was slower than the control group in reading sentences, especially with passive sentences. However, there were some dyslexic participants that were as fast as the control participants, thus indicating that they had developed adequate reading fluency despite their processing difficulties. Perhaps, most importantly, when discussing the results, a determinant factor is that this was a university-educated sample that possessed proper strategies in order to handle high demanding activities. Even though dyslexia is characterized by persistent literacy difficulties, there are cases when dyslexics can overcome these obstacles and become high achievers. Of course, this is not the norm, and this explains the overall slower performance of the dyslexic group in comparison to the control group.

The main objective of this investigation was to explore whether dyslexics demonstrate difficulties in processing sentences. As predicted, the dyslexic group showed more difficulties when processing passive sentences than active sentences. It was hypothesized that dyslexics would benefit more from a syntactic priming task compared to controls as a result of implicit learning (Bock & Griffin, 2000). Following an implicit learning account, language users come to process a structure more automatically when they have been previously exposed to this structure and they have implicitly learned something about the structure. The amount of learning corresponds to the magnitude of syntactic priming effects, which in turn determines the time-course of these effects (Jaeger & Snider, 2007).

Based on the analysis of reading times for passives, dyslexics demonstrated significant priming effects. There were no effects for actives. These findings answer the third research question and are consistent with Hypothesis 3. The fact that the magnitude of syntactic priming effects was stronger for passives suggests that dyslexic experienced more difficulties with this complex structure rather than active voice structure. Besides having a non-canonical word order, passive voice is less frequent than active voice, thus supporting the inverse frequency effect (Ferreira & Bock, 2006). In a similar vein, Jaeger and Snider (2007) state that syntactic priming effects are larger for a more unexpected syntactic structure because processing of such structure leads to greater expectations for the same structure, thus leading to more efficient processing. Such effects are not expected for structures like actives due to the high baseline frequency of processing such structures, thus leading to a ceiling effect in learning.

In the self-paced paradigm implemented in the experimental task, it was possible to explore how dyslexics processed each word of a sentence. The primary analysis of these data was focused on the critical region of passives composed by the auxiliary verb *to be*, the participle and the *by*-preposition because this region distinguishes the passive voice from the active voice and it was here where syntactic priming effects were awaited. The discussion of these results seem to be essential for a better understanding for syntactic processing in dyslexia.

The analysis of the critical region revealed that dyslexics showed a significant learning benefit from the repeated exposure to the passive voice structure. Initially, it was predicted that due to more difficulties in processing passives, the repeated exposure to this structure would be advantageous for dyslexics and would facilitate sentence processing (Fine & Jaeger, 2013). This facilitation would lead to immediate cumulative effects where reading fluency would increase gradually between individual prime and target sentences, i.e., reading of the second sentence would be faster than that of the first sentence, reading of the third sentence would be faster than that of the second, and so on. Indeed, processing of all target sentences was facilitated by processing of the surprisal (unexpected) prime sentence. These findings partially confirm Hypothesis 4 because the observed priming effects were not cumulative across all sentences of a mini-block. However, these effects were long lasting because dyslexics` processing of further sentences within a mini-block was also facilitated. The long-lasting effects are consistent with the account that syntactic priming is due to implicit learning (Bock & Griffin, 2000; Fine & Jaeger, 2013). Comparing to the control group, syntactic priming effects were significant for the third and fourth target sentences, thus indicating that this group did not have many processing difficulties with this infrequent structure.

When looking at the effects of syntactic priming in each word of the critical region, syntactic priming effects were detected across word 3, word 4, and word 5 for dyslexics, but not for controls. For the auxiliary verb, word 3, dyslexics showed priming effects for all target sentences, except for the fourth sentence. Reading fluency for word 3 increased gradually, but at sentence 4 there seemed to be a ceiling effect, i.e., dyslexics could not read faster than they had read in the third sentence. For the participle, word 4, the only significant effects were observed between the first prime sentence and the fourth target sentence. These results can be explained in terms of the results obtained for word 5, the *by*-preposition, with significant syntactic priming effects between the prime sentence and all target sentences.

According to Kaiser (2013), in a self-paced reading paradigm, the existence of spill-over effects are quite often. Spill-over effects reflect the impact when the region of interest processing and the impact of processing can be detected in a word or two after the region of interest, i.e., the spill-over region. In this case, word 4 (the participle) is the region of interest and what immediately follows word 4 refers to the spill-over region. Therefore, the absence of syntactic priming effects between the prime and other target sentences can be attributed to the presence of significant priming effects in the spill-over region (word 5). Similar results have already been reported in language comprehension studies (Traxler et al., 2014).

The results of Study III allow for the following conclusions. First, the above-discussed results provide evidence that syntactic priming in language comprehension is due to implicit learning (Bock & Griffin, 2000). More specifically, the more surprising prime structure, passive voice, rather than the more expected structure, active voice, led to stronger and long-lasting syntactic priming effects when processing later sentences with the same structure. In addition, the results have sought to contribute to the area of syntactic processing in dyslexia.

By conducting an experiment of reading comprehension with dyslexic adults, a good level of reading fluency was expected to be observed. A comparison of dyslexics and non-dyslexics in the processing of passives showed that dyslexics had difficulty with this complex structure. Importantly, dyslexics showed a greater learning benefit from being exposed to the more surprising structure than the control group, thus confirming the hypothesis of a syntactic processing deficit in dyslexia. These results are in line with previous studies, which also evidenced a syntactic processing weakness in dyslexics (Rüsseler, Becker, Johannes & Münte 2007; Wiseheart, Altmann & Lombardino, 2009; Leikin & Bouskila, 2004).

As regards the results of the control group, it was awaited to observe null or slight syntactic priming effects. Only the effects for the critical regions had a slight impact when they processed passive sentence. Such results can be explained by the fact that the control group contained typical readers without a syntactic processing weakness. Therefore, their learning benefit from syntactic priming was low as a very slight decrease in reading speed was observed.

As a whole, the results reported in the three studies seem to converge. In what follows, the next chapter entitled final remarks recaps the main findings of these studies as well as presents their limitations and suggestions for further research. In addition, I discuss educational, clinical and social implications of these studies.

CHAPTER VIII
FINAL REMARKS

The main objective of the present chapter is to summarize the most important findings of this dissertation that aimed at investigating behavioral and neuronal patterns of syntactic processing during language comprehension in dyslexic populations. More specifically, syntactic priming was used as a tool to answers questions about syntactic processing in dyslexic children as well as dyslexic adults. The main findings of the three studies reported in Chapters V through VIII are summarized and reviewed in section 8.1. Section 8.2 points out some limitations of these studies as well as proposes some suggestions on how further research should avoid these shortcomings. Finally, section 8.3 highlights the educational, clinical and social implications of these findings.

8.1 MAIN FINDINGS

As emphasized above, the three studies had the same main objective in common, i.e., to investigate syntactic processing in dyslexics during language comprehension. Studies I and II investigated syntactic priming effects in children and Study III focused on a population of adult dyslexics. In addition to that, comparing dyslexics` performance on the experimental task to that of the control group, it was sought to explore whether and to what extent dyslexics present weaknesses at the syntactic level. In order to achieve these objectives, two experimental tasks were carefully designed, one for dyslexic children and another for dyslexic adults. A summary of the main findings of this investigation is provided next.

Finding 1. Syntactic priming effects were greater for passives than for actives.

Passive sentences impose high syntactic processing demands due to the complexity of its structure. Active sentences have a canonical subject-verb-object order and have high frequency of occurrence both in oral and written modalities. By contrast, sentences in the passive voice have a non-canonical word order and are significantly less frequent than sentences in the active voice. In line with the well-established inverse frequency effect (Ferreira & Bock, 2006), stronger syntactic priming effects for passives rather than actives were expected to be observed. Along similar lines, Jaeger and Snider (2007) claim that syntactic priming effects are more evident for a less expected syntactic structure because its processing induces greater expectations for the same structure to occur later, thus leading to more efficient processing. Such surprisal sensitivity is not observed for structures like actives because the baseline frequency is very high. The results of the experiments carried out in the present dissertation show that indeed the magnitude of syntactic priming effects was greater for passive sentences rather than active sentences.

Finding 2. Syntactic priming effects were long lasting for the dyslexic group.

In the studies where the performance was compared between the groups, Study I and Study III, the magnitude of syntactic priming effects was stronger in the dyslexic group. In Study II, in which only dyslexics participated, strong syntactic priming effects were observed for passives, which were similar to those observed in Study I. Therefore, it is expected that the results of the control group to be submitted to the fMRI data collection will perform similar to the control group in Study I. The durability of syntactic priming effects is consistent with the account of implicit learning (Chang et al., 2006, 2000) and the results of Study I and Study II show that syntactic priming effects were long lasting and cumulative.

Finding 3.Dyslexics have a weaker syntactic representation of sentences in the passive voice than typical readers.

In the three experiments carried out in this dissertation, dyslexics demonstrated greater difficulty in processing passives rather than actives. In addition, they benefited more from being primed than the control group. With repetition, they were able to build a novel neural network for passives, which was not consolidated yet (Henson, 2003; Henson et al., 2000). These findings support a syntactic processing weakness in dyslexia and are in line with previous studies that show a deficit in syntactic processing in dyslexia (Leikin & Assayag-Bouskila, 2004; Rüsseler et al., 2007; Wiseheart et al., 2009).

Finding 4. Syntactic priming effects were greater for dyslexic children than dyslexic adults

The magnitude of syntactic priming effects for passives in dyslexic children and adults differed. Dyslexic children demonstrated stronger effects than adults with dyslexia and this evidence was not surprising. Taking into account that adult dyslexics were university students, and consequently, had more experience and contact with passive voice due to their reading and writing demands, this structure did not have such a strong impact on processing as it did for children. According Berman and Slobin (2013), adults use passive voice more often than children in a variety of situations, whereas children avoid using passives until quite late. A delayed acquisition of the passive structure in children is largely governed by the maturation of grammatical principles (Fox & Grodzinsky, 1998; Hirsch & Wexler, 2006). Therefore, adults' greater experience with the passive voice may account for the difference between children and adults in the magnitude of syntactic priming effects for passives found in the present dissertation.

Finding 5: Repetition enhancement represents learning and building novel networks for passives in the LIFG and LMFG.

Following Henson (2000), the repetition enhancement for passives observed in the LIFG and LMFG were associated with learning and building novel neural networks in the dyslexic brain for the passive structure. The results of Study II contribute to the evidence that this complex structure represents difficulties for dyslexics and its representation is not consolidated in dyslexics' brain. Through repetition, dyslexics are able to process passives more efficiently and automatically

All in all, the findings of this dissertation provide valuable contributions to the research on dyslexia. Syntactic processing is deficient in the dyslexic population. However, this population is able to learn implicitly from the repeated exposure to a complex sentence structure like the passive voice. These findings provide both encouraging and intriguing evidence for the area of dyslexia. Encouraging because it was possible to observe some beneficial effects of syntactic priming for dyslexics that can be employed in intervention programs. Intriguing because research into dyslexia has a short history compared to the research into other areas in psychology and linguistics and many issues related to language processing in general, and syntactic processing in particular, still needs to be addressed. There are still many questions waiting for answers. Future research involving both behavioral and neuronal measurements of syntactic processing can provide a better understanding of the phenomenon of dyslexia. Importantly, future research should consider the limitations of experiments carried out here. Next, I present the main limitations of this dissertation and offer suggestions that might contribute to more effective research design and more informative data.

8.2 LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The major innovation of this dissertation relies on providing a window onto how syntax is represented and processed in dyslexics. Despite the fact that the experimental design was carefully prepared and the experimental task was previously piloted, the present investigation suffered from a number of limitations and further research is needed to explore representations and workings of syntactic processing in the dyslexic population in the syntactic priming paradigm.

Limitation 1. The length of the experimental task

It is assumed that syntactic priming effects in language comprehension are subtle in comparison to language production. Therefore, in comprehension experiments a large amount of stimuli may be necessary to provide more consistent evidence for these effects. The original experimental task for children consisted of 200 sentences and for adults – 300 sentences. In both cases, general fatigue was observed which in turn might have produced an impact on task performance. In order to avoid this, it is suggested to apply the experimental task in two days or include a distracting activity in between.

Limitation 2. Reading comprehension assessment in Study I

The text used to assess reading comprehension in Study I was about wolves (Saraiva et al., 2006). The text describes the life of this animal and its characteristics and, according to the authors, was suitable for 5th graders. According to Saraiva e colleagues (2006), reading comprehension should be measured by texts which present new information about the world to the reader because the basic purpose of reading comprehension is to learn new information. Although wolves do not belong to the reality of the children who participated in Study I, the majority knew quite a lot about this animal when presented with its picture. This prior knowledge might have influenced the participants' general high comprehension of the text, especially in the group of dyslexics. Therefore, it is suggested to use a text which would bring completely new information, maybe a text about some exotic animal or some historic event not expected to be known by the sample. In addition, the dyslexics of Study I varied in age. There were participants at the age of 14 and 16 years, and of course, this text was not reliable to assess their reading comprehension skills. Thus, for future research, it is suggested to either control the age of the participants or use texts with appropriately challenging material for their age.

Limitation 3. Number of participants

The number of participants in Study I and Study III was quite similar. However, due to the limited funding available for the fMRI data collection, the number of participants in Study II had to be reduced significantly. Moreover, several participants had to be excluded due to extreme head motions. Therefore, future research should include a larger number of participants for the fMRI experiment considering these issues.

In addition, the fMRI study (Study II) did not count on the control group as in Study I and Study II. Thus, the comparison between two groups was not possible. In a future fMRI investigation, a control group is necessary to further investigate the neural correlates of syntactic priming effects during language comprehension.

Limitation 4. Intervening factors

Some intervening factors like socioeconomic status, intelligence, and age should be better controlled in future research. The three studies addressed these issues differently. In Study I, the questionnaire revealed important information about the participants' background and this information was used in the explanation of some results. In Study II, intelligence was thoroughly measured by using the battery of tests and intelligence served as a variable for classification of the dyslexic participants. In Study III, intelligence and working memory were broadly assessed by the battery of tests applied. Taking into account the findings of each study and in order to try to reduce disparities among participants within the same group to a minimum, further research should include a stricter control of these intervening factors as they definitely influence the way participants perform the experimental task.

8.3. EDUCATIONAL, CLINICAL AND SOCIAL IMPLICATIONS

The findings of the three studies carried out in this dissertation allow for the following educational, clinical and social implications. In relation to the school context, the findings underscore the idea that dyslexics do not have difficulty in conceptually interpreting the reading material. Although dyslexics took much more time to read sentences than controls, the majority of them were sufficiently accurate when responding to comprehension questions (80%-90%). These results show that dyslexics' reading can be as effective as that of other proficient readers, but for this, they need more time. For instance, the pedagogical implication here is that teachers can make the material available for dyslexic students in advance so that they can better accompany it on the day of presentation. Additionally, in order to optimize dyslexics' performance, teachers can provide extra time on the day of testing or give tests orally.

Moreover, I should put a special remark about the recruitment of dyslexic participants for Study I. Not all identified children with a formal diagnosis of dyslexia were selected to participate in the study. Due to severe reading difficulties, 37% of dyslexics had to be discarded. Great difficulties in decoding single words impeded these potential participants to perform the experimental task. This evidence raises an alarming educational issue because dyslexic children are in need of additional assistance in order to make progress in literacy skills. Although these children had already been diagnosed with dyslexia, it seems they lacked effective classroom instruction and/or intervention as their difficulties persisted. In Brazil, about 10% of school-age population is affected by dyslexia (Capovilla, Trevisan, Capovilla, & Rezende, 2007). This high percentage strongly suggests the necessity of trained teachers and support staff at schools to provide high quality intervention for this special population to overcome learning difficulties.

The results of the studies reported in the dissertation also have clinical implications. Despite the common association of dyslexia with the phonological deficit, the findings emphasize the importance of syntactic processing assessment in students with dyslexia. Therefore, early intervention should concentrate on the dyslexics` capacity to process sentences with different grammatical structures, in particular, complex structures such as the passive voice, which represents one of the troublesome issues in grammar instruction even for typically developing children. The experimental paradigm used in this dissertation showed that reading was facilitated and had long lasting effects when dyslexics had prior exposure to the same syntactic structure, highlighting thus the power of priming as an implicit-learning mechanism (Bock & Griffin, 2000). Hence, these findings suggest that dyslexics are prone to implicit learning and, in particular, can benefit from repeated exposure to syntactically challenging sentences.

Finally, the results of the present dissertation also allow for at least one social implication and this entails the importance of identifying and supporting children with dyslexia in countries like Brazil that, unfortunately, lack policies targeted at language learning difficulties. During the recruitment of dyslexic participants for Study I, various municipal and state schools in the Florianopolis region were contacted. In addition, the Municipal Department for Education of Florianópolis as well as the Santa Catarina State Department for Education were also contacted with an expectation to obtain official data about dyslexic students in the region. However, the Municipal Department for Education of Florianopolis possessed a record of only five dyslexic students and the State Department for Education did not have any information about dyslexics. This evidence apparently reflects no systematic monitoring of school-age children with dyslexia, thus raising an alarming social issue where dyslexic children are being neglected by the local authorities.

Consequently, these children grow as adults whose quality of life in the literate society remains poor.

All in all, these limitations and suggestions are not conclusive, but they are important to consider for further research. Despite the shortcomings that I detected, I believe that the findings of the studies reported in the present dissertation have contributed to enlighten, at least a bit, the understanding of how dyslexics process written sentences on-line and that their processing is facilitated by syntactic priming to the same degree as in peers without dyslexia at the behavioral and neuronal levels.

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APPENDIX A

A1: Consent form for the participant's legal guardian – Study I

UFSC

Universidade Federal de Santa Catarina – UFSC
Centro de Comunicação e Expressão
Pós-Graduação em Inglês – Estudos Linguísticos e Literários
Instrumentos de Pesquisa

Pesquisa: **OS EFEITOS DE PRIMING SINTÁTICO NA COMPREENSÃO DE FRASES EM PORTUGUÊS DO BRASIL: UM ESTUDO COMPARATIVO ENTRE CRIANÇAS COM DISLEXIA E SEM DISLEXIA**

Doutoranda: Anna Belavina Kuerten
Orientadora: Drª Mailce Borges Mota

Termo de Consentimento Livre e Esclarecido para o responsável

Pesquisa: **OS EFEITOS DE PRIMING SINTÁTICO NA COMPREENSÃO DE FRASES EM PORTUGUÊS DO BRASIL: UM ESTUDO COMPARATIVO ENTRE CRIANÇAS COM DISLEXIA E SEM DISLEXIA**

Senhores Pais/Responsáveis,

Eu, Anna Belavina Kuerten, aluna de doutorado do Programa de Pós-Graduação em Inglês – Estudos Linguísticos e Literários, sob orientação da professora Dra. Mailce Borges Mota na Universidade Federal de Santa Catarina – UFSC, convido você e seu/sua filho/a a participar na minha pesquisa.

O objetivo da pesquisa é investigar a leitura por crianças com diagnóstico de dislexia. A sua leitura será comparada com a de crianças sem diagnóstico de dislexia da mesma faixa etária de 10 a 12 anos. Os estudos nessa área visam não só compreender como a criança disléxica lê, mas também podem contribuir para os possíveis meios de intervenção com o propósito de melhorar a sua qualidade de vida. Acreditamos que essa pesquisa seja importante porque ainda são poucos os estudos realizados com crianças diagnosticadas com dislexia no Brasil.

Se você concordar e autorizar o menor, sob sua responsabilidade, em participar desta pesquisa, primeiramente você assinará o presente termo de consentimento livre e esclarecido e responderá ao questionário com as informações gerais sobre seu/sua filho/a, bem como as informações de saúde, informações escolares e sociais. A criança fará uma tarefa de leitura com frases curtas em português na tela de um computador e responderá a eventuais perguntas de compreensão (sim ou não) apertando uma das teclas no computador. Esta tarefa terá duração aproximada de 30 a 60 minutos.

Nós certificaremos de que o ambiente de aplicação da tarefa ofereça condições satisfatórias para a sua execução (iluminação, temperatura e posicionamento adequado do monitor do computador de acordo com a sua altura e cadeira confortável) evitando as influências externas como ruídos e interrupções. É possível que aconteça um certo desconforto, como cansaço visual, o que tentamos evitar dividindo a tarefa em duas partes e propondo um intervalo de 10 minutos. No caso de algum desconforto durante a realização da tarefa, a criança pode interrompê-la a qualquer momento.

Os benefícios que esperamos com o estudo são aumentar os conhecimentos sobre como a criança disléxica lê e compreende as frases em português. Esses dados podem contribuir para o processo de aprendizagem da leitura por crianças disléxicas.

Todos os dados desta pesquisa serão confidencias, e serão divulgados apenas em eventos ou publicações científicas, não havendo identificação dos participantes. Os dados serão guardados em local seguro e após 5 anos serão incinerados.

Informo que durante todo o período da pesquisa o Sr(a) tem a garantia de acesso, em qualquer etapa do estudo, a qualquer esclarecimento sobre o estudo. Caso sinta-se incomodado/a, pode pedir para pararmos o procedimento no momento necessário, sem qualquer prejuízo ou punição para você e/ou seu/sua filho/a. Não existirão despesas e/ou compensações pessoais para o participante em qualquer fase do estudo.

O projeto dessa pesquisa foi avaliado e aprovado pelo Comitê de Ética em Pesquisa em Seres Humanos do Hospital Infantil Joana de Gusmão (HIJG). Um Comitê de Ética em Pesquisa em Seres Humanos (CEP) é composto por um grupo de pessoas que estão trabalhando para garantir que seus direitos como participante de pesquisa sejam respeitados. Ele tem a obrigação de avaliar se a pesquisa foi planejada e se está sendo executada de forma ética. Se você achar que a pesquisa não está sendo realizada da forma como você imaginou ou que está sendo prejudicado de alguma forma, você pode entrar em contato com o CEP do HIJG pelo telefone 48 – 32519092 ou pelo email: cephijg@saude.sc.gov.br . Você pode inclusive fazer a reclamação sem se identificar, se preferir.

Contatos dos pesquisadores

Tendo qualquer dúvida sobre a pesquisa e/ou os procedimentos, você pode entrar em contato com Anna Belavina Kuerten, pelo email xxxxxx ou pelo telefone xxxxxx , ou com a professora Dra. Mailce Borges Mota através do email xxxxxx , telefone xxxxxx , ou no prédio do Centro de Comunicação e Expressão – CCE, xxxxxx Universidade Federal de Santa Catarina, UFSC.

Anexo está o consentimento livre e esclarecido para ser assinado caso não tenha ficado qualquer dúvida.

Termo de Consentimento Livre e Esclarecido para o responsável

Permito a participação do (a) meu (minha) filho (a) na pesquisa **OS EFEITOS DE PRIMING SINTÁTICO NA COMPREENSÃO DE FRASES EM PORTUGUÊS DO BRASIL: UM ESTUDO COMPARATIVO ENTRE CRIANÇAS COM DISLEXIA E SEM DISLEXIA,** de autoria de Anna Belavina Kuerten.

Estou ciente que posso retirar o meu consentimento a qualquer momento, antes ou durante a pesquisa, sem penalidade, prejuízo ou perda de qualquer benefício que eu ou a/a meu/minha filho/a possa ter adquirido/a. Esses dados são apenas para certificação de quem está assinando é efetivamente responsável pela criança.

_______________________________ Data ______/_____/_____
Assinatura do pai (mãe) ou responsável

Nome: ____
RG. Ou CPF:__________________________
Fone: ( )_____________________________

_______________________________ Data ______/_____/_____
Assinatura do (a) pesquisador (a)

Nome da criança:____________________________________

Em caso de dúvidas com respeito aos aspectos éticos desta pesquisa, você poderá consultar:
CEP - Comitê de Ética em Pesquisa em Seres Humanos
Hospital Infantil Joana de Gusmão (HIJG)
Endereço: Rui Barosa, 152 – Agronômica – Florianópolis – SC – 88025-301
Fone: (48) 3251-9092/ E-mail: cephijg@saude.sc.gov.br

A2: Consent form for the participant – Study I

Termo de Assentimento Livre e Esclarecido para o participante

Caro aluno

Convidamos você a participar de uma pesquisa **OS EFEITOS DE PRIMING SINTÁTICO NA COMPREENSÃO DE FRASES EM PORTUGUÊS DO BRASIL: UM ESTUDO COMPARATIVO ENTRE CRIANÇAS COM DISLEXIA E SEM DISLEXIA.**

O objetivo dessa pesquisa é descobrir como a criança na sua idade lê.

Como vamos descobrir isso? Contando com a sua participação na pesquisa.

O que você vai precisar fazer? Ler silenciosamente as frases que serão apresentadas palavra por palavra num monitor do computador. Você vai apertar a barra de espaço para isso. Após algumas frases você vai ver as perguntas sobre a frase anterior que têm que ser respondidas como "sim" ou "não".

A tarefa tem duas partes. Após a primeira parte você vai ter um intervalo de 10 minutos. É possível que você se sente cansado(a) durante a tarefa. Se isso acontecer, você pode parar para descansar um pouco. As duas partes da tarefa demoram de 30 a 60 minutos.

O seu nome não vai ser divulgado para ninguém. Você não vai ter nenhum gasto para participar dessa pesquisa. Caso queira parar a tarefa por algum motivo, você não será prejudicado/a.

Você será um grande colaborador da Profa. Anna Belavina Kuerten e para a ciência.

______________________________ Data _____/_____/_____

Assinatura e nome do (a) participante

______________________________ Data _____/_____/_____

Assinatura do (a) pesquisador (a)

A3: Consent form for the participant's legal guardian – Study II

TERMO DE ASSENTIMENTO E CONSENTIMENTO LIVRE E ESCLARECIDO

PROJETO ACERTA (Avaliação de Crianças Em Risco de Transtorno de Aprendizagem)

PESQUISADOR RESPONSÁVEL: Prof. Dr. Augusto Buchweitz – Instituto do Cérebro, PUCRS

Seu filho/filha está sendo convidado a participar de uma pesquisa sobre leitura e sobre o funcionamento do cérebro. O objetivo da pesquisa é entender como o cérebro funciona enquanto a criança lê palavras e frases. Para descobrir isso, crianças que estejam em idade escolar e entre o 5º e o 7º ano, como seu filho(a), estão sendo convidadas a participar da pesquisa. Caso o(a) sr.(a) dê sua autorização, seu filho fará alguns testes de leitura na escola para avaliar como está a leitura dele e, depois, poderá fazer um exame de ressonância magnética do cérebro. Todas as crianças da escola farão os testes de leitura, algumas farão o exame do cérebro. Durante o exame, seu filho ficará deitado na máquina de ressonância enquanto olha um televisor no qual aparecerão algumas palavras, frases ou textos para ler; também serão feitos exames de ressonância que permitem analisar o cérebro do seu filho e durante os quais ele não precisa fazer nada. O único incômodo do exame é um ruído, mas ele estará usando tampões ou fones de ouvido para diminuir o barulho. A ressonância magnética não faz mal à saúde. Ela não utiliza radiação, como o raio-x e a tomografia. Às vezes, porém, o exame pode gerar um pouco de angústia ou preocupação, pois algumas crianças sentem-se mal por ficar paradas dentro da máquina durante alguns minutos. Se isso acontecer, não há problema; o exame pode ser parado pela própria criança a qualquer momento caso não queira continuar.

Benefícios: Não há benefício direto para as pessoas que participarem deste estudo, mas elas estarão ajudando outras pessoas a entender melhor o funcionamento do cérebro enquanto leem.

Sigilo e privacidade: Todas as informações da pesquisa serão guardadas pelos pesquisadores e só eles terão acesso a essas informações. O nome do seu filho não será utilizado; apenas códigos, como letras e números, serão usados para identificar os dados. Quando esses dados forem usados em textos, aulas e cursos ninguém poderá identificar a pessoa a quem pertencem. Despesas e compensações: Se houver algum gasto de dinheiro com transporte/deslocamento ao Instituto do Cérebro, esse gasto será pago pelos pesquisadores (até um limite de R$ 40,00 reais por participante).

Se houver perguntas sobre esse estudo, favor entrar em contato com o Prof. Dr. Augusto Buchweitz no seguinte endereço: Instituto do Cérebro, Av. Ipiranga, 6690; Partenon; Porto Alegre/RS. Fone: 3320-3485 ramal 2693 ou o Comitê de Ética em Pesquisa da PUCRS: Av. Ipiranga 6681, Prédio 40 – Sala 505, Porto Alegre /RS - Brasil - CEP: 90619-900; Fone/Fax: (51) 3320.3345; E-mail: cep@pucrs.br

Acredito ter sido suficientemente informado a respeito das informações que li ou que foram lidas para mim, descrevendo o estudo. Ficaram claros para mim quais são os objetivos do estudo, os procedimentos a serem realizados, seus desconfortos e riscos, as garantias de proteção dos meus dados e de esclarecimentos permanentes. Concordo voluntariamente na participação de meu filho e poderei retirar o meu consentimento a qualquer momento, antes ou durante o mesmo, sem penalidades ou prejuízo ou perda de qualquer benefício que eu possa ter adquirido, ou no meu atendimento neste Serviço.

Dou meu consentimento de espontânea vontade e sem reservas para que meu filho (a) .... (nome por extenso do filho(a)) possa participar deste estudo. Este documento será assinado em duas vias.

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Assinatura do representante legal	Assinatura do pesquisador responsável

Data / /

A4: Consent form for the participant – Study II

TERMO DE ASSENTIMENTO E CONSENTIMENTO LIVRE E ESCLARECIDO

<u>PROJETO ACERTA (Avaliação de Crianças Em Risco de Transtorno de Aprendizagem)</u>

PESQUISADOR RESPONSÁVEL: Prof. Dr. Augusto Buchweitz – Instituto do Cérebro, PUCRS

Você está sendo convidado a participar de uma pesquisa sobre leitura e sobre o funcionamento do cérebro. O objetivo da pesquisa é entender como o cérebro funciona enquanto você lê palavras e frases. Para descobrir isso, crianças como você estão sendo convidadas a participar da pesquisa. Se você aceitar participar, você fará alguns testes de leitura na escola para avaliar como está a leitura dele e, depois, poderá fazer um exame de ressonância magnética do cérebro. Todas as crianças da sua escola que aceitarem farão os testes de leitura, mas só algumas farão o exame do cérebro. Durante o exame, você ficará deitado na máquina de ressonância enquanto olha um televisor no qual aparecerão algumas palavras, frases ou textos para ler; também serão feitos exames de ressonância que permitem analisar o seu cérebro e durante os quais você só precisa descansar. O único incômodo do exame é um ruído alto, mas você estará usando tampões ou fones de ouvido para diminuir o barulho. A ressonância magnética não faz mal à saúde. Ela não utiliza radiação, como o raio-x e a tomografia. Às vezes, porém, o exame pode gerar um pouco de angústia ou preocupação, pois algumas pessoas sentem-se mal por ficar paradas dentro da máquina durante alguns minutos. Se isso acontecer, não há problema; você pode parar o exame a qualquer momento caso não queira continuar.

Benefícios: Não há benefício direto para as pessoas que participarem deste estudo, mas a sua participação ajudará a entender melhor o funcionamento do cérebro enquanto você lê.

Sigilo e privacidade: Todas as informações da pesquisa serão guardadas pelos pesquisadores e só eles terão acesso a essas informações. O seu nome não será utilizado; apenas códigos, como letras e números, serão usados para identificar os dados do seu exame e dos seus testes. Quando esses dados forem usados em textos, aulas e cursos ninguém poderá identificar a pessoa a quem pertencem. Despesas e compensações:

Se houver algum gasto de dinheiro com transporte/deslocamento ao Instituto do Cérebro, esse gasto será pago pelos pesquisadores (até um limite de R$ 40,00 reais por participante).

Se houver perguntas sobre esse estudo, favor entrar em contato com o Prof. Dr. Augusto Buchweitz no seguinte endereço: Instituto do Cérebro, Av. Ipiranga, 6690; Partenon; Porto Alegre/RS. Fone: 3320-3485 ramal 2693 ou o Comitê de Ética em Pesquisa da PUCRS: Av. Ipiranga 6681, Prédio 40 - Sala 505 Porto Alegre /RS - Brasil - CEP: 90619-900; Fone/Fax: (51) 3320.3345; E-mail: cep@pucrs.br

Acredito ter sido suficientemente informado a respeito das informações que li ou que foram lidas para mim, descrevendo o estudo. Ficaram claros para mim quais são os objetivos do estudo, os procedimentos a serem realizados, seus desconfortos e riscos, as garantias de proteção dos meus dados e de esclarecimentos permanentes. Concordo voluntariamente com a participação e poderei retirar o meu consentimento a qualquer momento, antes ou durante o mesmo, sem penalidades ou prejuízo ou perda de qualquer benefício que eu possa ter adquirido, ou no meu atendimento neste Serviço.

Dou meu consentimento de espontânea vontade e sem reservas para participar deste estudo. Este documento será assinado em duas vias.

--	------------------------------------
Assinatura do representante legal	Assinatura do pesquisador responsável

Data / /

APPENDIX B

Questionnaire about the participant's background – Study I

CÓDIGO: __________

QUESTIONÁRIO

(para ser preenchido por pesquisador)

UNIVERSIDADE FEDERAL DE SANTA CATARINA
CENTRO DE COMUNICAÇÃO E EXPRESSÃO
DEPARTAMENTO DE LÍNGUA E LITERATURA ESTRANGEIRAS
Programa de Pós Graduação em Inglês: Estudos Linguísticos e Literários

Este questionário é parte do estudo intitulado "OS EFEITOS DE PRIMING SINTÁTICO NA COMPREENSÃO DE FRASES EM PORTUGUÊS DO BRASIL: UM ESTUDO COMPARATIVO ENTRE CRIANÇAS COM DISLEXIA E SEM DISLEXIA" que eu, Anna Belavina Kuerten, estou conduzindo, sob a orientação da professora Dra. Mailce Borges Mota. Agradeço a sua participação, que é de extrema importância para a realização desse estudo.

INFORMAÇÃO SOBRE O PARTICIPANTE

Idade: ____ Sexo: M( ) F( )

INFORMAÇÃO SOBRE O(S) RESPONSÁVEL(IS)

1. Sua relação com a criança é de: Pai/Mãe( ) Padrasto/Madrasta( ) Avô/Avó( ) Outra ______________
2. Idade: _____________ Profissão:________________
3. Horário de trabalho: Manhã( ) Tarde( ) Noite( ) Manhã e Tarde( ) Tarde e Noite( ) Noite e Manhã ( )
4. Escolaridade: 1º Incompleto( ) 1º Completo( ) 2º Incompleto( ) 2º Completo( ) Superior Incompleto( ) Superior Completo( ) Nunca frequentou a escola ( )
5. Estado Civil: Solteiro(a)( ) Casado(a)( ) Divorciado(a)( ) Viúvo(a) ( )
   Em caso de divórcio entre os pais] A guarda da criança é compartilhada? Sim( ) Não( )

O(a) pai/mãe paga pensão? Sim ( ) Não ( )
6. O responsável tem a religião? Sim ( ) Não ( ) Qual? ______________
7. A criança participa de alguma religião? Sim( ) Não( ) Qual? ________
8. Quantos filho o(a) Sr(a) têm? ____Quantos moram com o(a) Sr(a)?___
9. Essa criança reside/convive há quanto tempo com o(a) Sr(a)? ______
10. Essa criança é adotiva? Sim ( ) Não( )
Se sim, há quanto tempo?____________
11. A posição dessa criança entre os seus irmãos é:
Caçula( ) Mais velha( ) 2ª( ) 3ª( ) Outra ___________
12. Alguém na sua residência recebe auxilio-financeiro do governo (por ex, Bolsa Familia ou auxilio-invalidez? Sim ( ) Não ( )
Quais? __________________________________
13. Renda Familiar da casa: 1 Salário Mínimo ( ) 2 S.M.( ) 3 S.M. ( ) 4 S.M.( ) 5 S.M.( ) 6 S.M.( ) 7 S.M.( ) 8 S.M.( ) Outro ______
14. Há um segundo responsável pela criança? Sim( ) Não( )
15. Sua relação com a criança é de: Pai/Mãe( ) Padrasto/Madrasta( ) Avô/Avó( ) Outra _____________
16. Idade:_________________ Profissão: _________________
17. Horário de trabalho: Manhã( ) Tarde( ) Noite( ) Manhã e Tarde( ) Tarde e Noite( ) Noite e Manhã( )
18. Escolaridade: 1º Incompleto( ) 1º Completo ( ) 2º Incompleto( ) 2º Completo( ) Superior Incompleto( ) Superior Completo( ) Nunca frequentou a escola ( )
19. Estado Civil: Solteiro(a)( ) Casado(a)( ) Divorciado(a)( ) Viúvo(a) ( )
20. O 2º responsável tem a religião? Sim ( ) Não ( ) Qual? ___________
21.Essa criança reside/convive há quanto tempo com esse responsável?_______ Não reside ( )

INFORMAÇÕES DE SAÚDE

1. Possui algum problema de saúde (físico/psicológico)*?

* Investigar fatores que influenciem na frequência e/ou desempenho escolar. por exemplo: asma, bronquite, dores de garganta e ouvido recorrentes, problemas gastrointestinais como diarréia e vômitos recorrentes, anemia, diabetes, alergias de pele e em geral, dores de cabeça frequentes, TDAH, outras doenças psiquiátricas, más-formações congênitas, síndrome de Down...

a. Sim ( ) Qual(is)? _________________________________
b. Não ( )

2. Utiliza algum medicamento de forma contínua?

a. Sim ( ) Qual(is)?___________________________________
b. Não ( )

3. Há histórico de doenças psiquíatricas e/ou deficits e transtornos de aprendizagem na familia?
   a. Sim ( ) Qual(is) e em quem (parentesco)?_______________
   b. Não ( )
4. Quais as doenças teve na infância e com que idade?
   Sarampo ( ) Rubéola ( ) Caxumba ( ) Poliomielite ( ) Varicela (catapora) ( ) Meningite ( ) Pneumonia ( ) Diarréia ( ) Coqueluche ( ) Tuberculose ( )
5. Está com a vacinação em dia?
   a. Sim ( )
   b. Não ( ) Qual(is) falta(m)? _______________________
6. Tem problema de visão?
   a. Sim e usa óculos ( ) Qual(is)? _______________________
   Há quanto tempo foi a última consulta com oftalmologista? _________________
   b. Sim, mas não usa óculos ( ) Qual(is)? ___________________
   c. Não ( )

7. Peso e Altura: ________________

8. Quantidade de refeições diárias:
   ( ) uma ( ) duas ( ) três ( ) quatro ( ) cinco ou mais
9. Come antes de vir à escola?
   a. Sim ( ) O quê? _________________________
   b. Não ( )
10. Horas de sono diário: 12 ou mais( ) 10 a 12( ) 8 a 10( ) 6 a 8( ) 4 a 6( ) menos de 4( )
11. Compartilha o quarto com alguém? Sim ( ) Não ( )
12. Ocorreu algum acidente ou fato marcante na vida da criança?
    a. Sim ( ) Qual? __________________________________
    b. Não ( )
13. Peso ao nascer: ______________
14. Recebeu leite materno durante quanto tempo?
    a. Exclusivo ( )
    b. Complementado ( ) Qual? ______________________
15. Apresentou algum problema de desenvolvimento nos primeiros meses de vida?
    a. Sim ( ) Qual(is)? _______________________________
    b. Não ( )

INFORMAÇÕES ESCOLARES

Ano: _______ Turma: _______
Tempo que a frequenta a escol atual:___________
Período: Matutino ( ) Vespertino ( )
1. Frequência Escolar: Boa ( ) Falta muito ( )
Repetiu alguma vez na escola atual? a. Sim ( ) Nº. vezes por série _____
b. Não( )
2. Escolas anteriores: ________________________
Repetência? a. Sim ( ) Nº. vezes por série
b. Não ( )
3. [Em caso de repetência] As principais razões foram para a repetência foram: Frequência( ) Comportamento( ) Notas( ) Mudanças ( )
Saúde ( ) Outra ________________________
4. Em casa há alguém que o auxilie nos estudos?
a. Sim ( ) Quem? __________________
b. Não ( )

INFORMAÇÕES SOCIAIS

1. Reside em: Casa( ) Apartamento( )
2. Reside em Zona: Rural( ) Urbana( )
3. O imóvel em que reside é: Próprio( ) Alugado( ) Cedido( )
4. Há quanto tempo reside neste local: _______________________
5. Outros locais em que morou:_____________________________
6. Quantas pessoas moram na residência? Três( ) Quatro( ) Cinco( ) Seis ou mais( )
7. Local de permanência no contra-turno:_____________________
8. Tem que cuidar de alguém?
   a. Sim ( ) Irmã(os) ( ) Amigos(as) ( ) Outros_______
   b. Não ( )
9. Faz as tarefas domésticas?
   a. Sim ( ) Quais tarefas?____________________________
   Com que frequência?______________________
   b. Não ( )
10. Meio de locomoção para a escola:
Ônibus ( ) Carro ( ) A pé ( ) Outro ( ) ____________
11. Tempo de locomoção até o colégio: Menos de 10 mins ( ) de 10 a 20 mins ( ) de 20 mins a 30 mins ( ) de 30 a 40 mins ( ) mais de 40 mins ( )
12. Possui computador e acesso à internet?

Ambos ( ) Apenas computador ( ) Nenhum dos dois ( )

13. Possui vídeo-game? Sim ( ) Não ( )
14. Quanto tempo diário gasto com Internet/video game?
    Até 30 mins ( ) de 30 mins a 1 hora ( ) de 1 a 2 horas ( )
    mais de 2 horas ( )
15. Como é o relacionamento da criança com pais, irmãos, amigos e outros?
16. Pratica esportes?
    a. Sim ( ) Qual? ________________________________
       Quantas vezes por semana?________________
       Durante quanto tempo? ____________________
    b. Não ( )
17. Responsáveis têm o hábito de ler?
    a. Sim ( ) Livros( ) Jornais ( ) Revistas ( )
       Outros ____
    b. Não ( )

Muito obrigada pela participação!

APPENDIX C

C1: Instructions for teachers to assess experimental stimuli (Study I)

Avaliação das frases em Português no passado

Caro(a) professor(a),

No intuito de escolhermos as frases no passado para um experimento que será aplicado com crianças de 10 à 12 anos gostaríamos de receber a sua avaliação quanto ao aspecto de compreensão da frase pela criança (ao lê-lá não causará estranhamento ou dificuldade para a criança).

Sendo assim, solicitamos que realize a leitura cuidadosa das sentenças e as classifique marcando:

1 - totalmente inaceitável se a frase não apresentar clareza, não for compreensível

2 - inaceitável se a frase não apresentar clareza, for difícil de compreender

3 - neutra se a frase causar estranhamento e você estiver na dúvida quanto à avaliação da mesma.

4 - aceitável se a frase apresentar clareza e for compreensível, mas não é do cotidiano da criança.

5 - totalmente aceitável se a frase apresentar clareza e for compreensível, além disso, é do cotidiano da criança.

Caso você marque 1, 2 ou 3 para as frases, solicitamos que aponte o problema para que possamos fazer a alteração e, assim, tornar a sentença apropriada para a faixa etária de 10 a 12 anos. Ressaltamos que a sua colaboração para o sucesso do nosso experimento é de fundamental importância.

Contamos com o seu auxílio e agradecemos pela sua atenção!

Frase	**Avaliação**					**Observação**
	1	**2**	**3**	**4**	**5**	
A criança derrubou a lata.						
O morador derrubou o vaso.						
O cidadão derrubou a moto.						
O jogador derrubou a trave.						
A esposa derrubou o copo.						
O pintor conheceu o público.						
O leitor conheceu a autora.						

....

C2: Instructions for children to assess experimental stimuli (Study I)

Nome:__________

Caro(a) aluno(a),

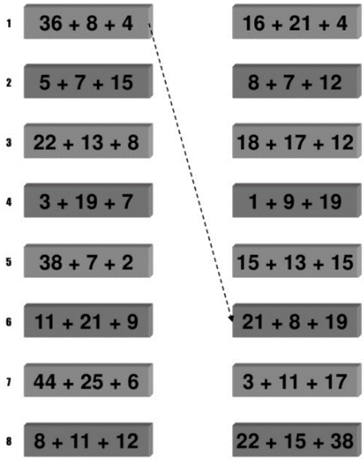
Gostaríamos de receber a tua opinião sobre as frases listadas abaixo. Cada frase tem que ser lida com atenção e avaliada com uma carinha feliz ☺ (compreensível/boa) ou uma carinha indiferente 😐 (nem boa, nem ruim) ou uma carinha infeliz ☹ (não compreensível/ ruim). Somente uma carinha pode ser marcada.

Contamos com o teu auxílio e agradecemos pela tua atenção!

Frase	☺	😐	☹
A frase ficou muito longa.			
O álbum ficou muito lindo.			
O quarto ficou muito limpo.			
O carro ficou muito melhor.			
A carta ficou muito boa.			

....

Une os resultados iguais



C3: Instructions for university students to assess experimental stimuli (Study III)

Dear participant,

We are going to conduct a research on sentence processing and comprehension with young adults. In order to select sentences for our experiment, we would like to receive your opinion about them.

What you should do is very simple! You will need to follow these instructions:

- Carefully read each sentence
- Rate the sentence according the scale from 1 to 5.

A 5-point scale:

1. Totally unacceptable if the sentence is not understandable/ ungrammatical.
2. Unacceptable if the sentence is not clear/ hard to understand
3. Neither unacceptable nor acceptable (undecided)
4. Acceptable if the sentence is clear/understandable but you would not say/write this way.
5. Totally acceptable if the sentence is clear/understandable, it is common that you say/write this way.

Your collaboration is fundamental for our experiment!

THANK YOU☺

APPENDIX D

D1: Illustration for the reading comprehension task (Saraiva et al, 2006)

D2: Text for the reading comprehension task with guiding questions (Saraiva et al, 2006)

Os lobos

O lobo é um dos mamíferos carnívoros mais espertos e ferozes que existe.

Ele ainda é encontrado nas florestas e campos da Sibéria, da Escandinávia, da Ásia e parte da América do Norte.

Seu corpo magro, mas forte, suas longas pernas, próprias para corridas rápidas, uma ótima visão, uma audição extremamente aguçada e dentes poderosos, lhe permitem perseguir e pegar a presa com facilidade, sendo um exímio caçador.

Durante o inverno, quando o alimento escasseia, os lobos se juntam para caçar, formando bandos de até doze indivíduos. O bando é super organizado e costuma caçar a noite. Quando descobre a presa, como um veado, um porco ou uma ovelha, ataca comandado pelo chefe do bando. Os lobos sabem fugir das armadilhas e, ao caminhar pela neve, um atrás do outro, colocam suas patas sobre as pegadas do lobo que vai à frente. Eles conseguem comer de cinco a seis quilos de carne na refeição, mas mostram sua ferocidade ao matar, algumas vezes, mais presas do que são capazes de comer.

Já durante a primavera e o verão, os lobos se acasalam e, depois de dois meses, nascem os filhotes. A mãe amamenta os filhotes e cuida deles por vários meses, ajudada pelo macho. Neste período, eles não vivem em bandos. O casal permanece junto pelo resto da vida.

Há muito tempo atrás, quando os homens começaram a ocupar o território dos lobos, estes passaram a atacar pessoas e rebanhos. Foram caçados impiedosamente e, como consequência, entraram para a lista de animais quase em extinção.

Perguntas orientadoras como ajuda para a compreensão do texto:

1) Qual a classe de animais a que pertence o lobo?

2) Qual seu habitat atualmente?

3) Quais as características físicas do lobo que o fazem um exímio caçador?

4) Por que eles se juntam em bando no inverno?

5) Por que o lobo é considerado um dos mamíferos carnívoros mais ferozes e espertos que existe?

6) Quais os hábitos dos lobos na primavera/verão?

7)Qual a diferença de comportamento dos lobos no inverno e na primavera/verão?

8) Por que o lobo é um animal quase em extinção?

9) Por que os lobos, ao caminharem na nave, pisam um na pegada do outro?

10) Como eles se alimentam na primavera/verão, se não ficam em bando para caçar?

APPENDIX E

E1: List of sentences for Study I

O moleque disse o segredo.
O diretor disse o problema.
O professor disse a resposta.
O artista disse a notícia.
O café foi bebido pela senhora.
O suco foi bebido pela criança.
A coca foi bebida pelo menino.
A água foi bebida pelo animal.
O leite foi bebido pelo gatinho.
O frio chegou mais cedo.
A irmã chegou de manhã.
O verão chegou com tudo.
A lição foi estudada pelo aluno.
A frase foi estudada pela filha.
A dança foi estudada pela prima.
O texto foi estudado pelo grupo.
A ideia foi estudada pelo rapaz.
O doutor descobriu o vírus.
A raposa descobriu a toca.
A coruja descobriu o bosque.
O lugar foi procurado pela pessoa.
O homem foi procurado pelo guarda.
O aluno foi procurado pela escola.
O ninho foi procurado pela coruja.
O balão foi procurado pelo mágico.
A guria brincou na praça.
O pequeno brincou no berço.
O grupo brincou no pátio.
O rapaz brincou de herói.
O ator brincou no palco.
A cabra brincou no pasto.
A cantora brincou com público.
O livro foi escrito pelo homem.
A ideia foi escrita pelo filho.
A carta foi escrita pela prima.
A prova foi escrita pelo aluno.
A frase foi escrita pela amiga.
O álbum ficou muito lindo.
O quarto ficou muito limpo.
A carta ficou muito boa.
O preço ficou muito alto.
A aula ficou muito interessante.
O jardim ficou muito legal.
O tapete foi colocado pela mulher.
O quadro foi colocado pela prima.
A janela foi colocada pelo rapaz.
A sacola foi colocada pela titia.
O açúcar foi colocado pela filha.
O filho fugiu de casa.
O pássaro fugiu da gaiola.
O leão fugiu do circo.
O ladrão fugiu da prisão.
O jornal foi lido pela babá.
A página foi lida pelo moço.
O título foi lido pelo vovô.
O cartaz foi lido pelo povo.
A sílaba foi lida pela irmã.
O trânsito andou bem devagar.
O idoso andou com ajuda.
O patinho andou em grupo
O turista andou bem feliz.
O caminhão andou bem rápido.
A tribo andou pela floresta.
A galera andou pela cidade.
A banana foi comida pelo macaco.
A salada foi comida pela garota.
A cenoura foi comida pelo coelho.
A cereja foi comida pela senhora.
O açúcar foi comido pela barata.
A namorada ganhou o cachorro.
O bombeiro ganhou o diploma.
A garotinha ganhou a sandália.
O comprador ganhou a viagem.
A madrinha ganhou o vestido.

O carteiro ganhou o presente.
O nome foi dado pela mamãe.
O anel foi dado pelo homem.
A flor foi dada pela filha.
A vela foi dada pela índia.
O doce foi dado pelo papai.
O livro caiu no chão.
A chave caiu da mão.
O prato caiu da mesa.
A roupa caiu da cama.
O dente caiu da boca.
A moeda caiu do bolso.
A notícia foi contada pelo jornal.
O desenho foi contado pela mulher.
O caminho foi contado pelo guarda.
O passeio foi contado pelo senhor.
O anúncio foi contado pela pessoa.
O moleque subiu o morro.
O morador subiu a escada.
O mercado subiu o preço.
O capitão subiu na torre.
O elevador subiu o andar.
A prova foi feita pelo aluno.
A festa foi feita pela turma.
A magia foi feita pela bruxa.
A massa foi feita pela mamãe.
O ninho foi feito pelo sabiá.
A atriz pegou o vestido.
O padre pegou a bíblia.
A jovem pegou o filme.
O jogador pegou a bola.
O morador pegou o lixo.
O estudante pegou o livro.
O pano foi lavado pela mamãe.
A meia foi lavada pela filha.
O chão foi lavado pela mulher.
A maçã foi lavada pelo irmão.
O bote foi lavado pelo amigo.
O atleta dormiu até tarde.
O trabalhador dormiu bem mal.
A colega dormiu no serviço.
O estudante dormiu poucas horas.
A sogra dormiu em casa.
O ganso dormiu na grama.
A barata foi vista pela irmã.
A garota foi vista pela babá.
A ovelha foi vista pelo lobo.
A rainha foi vista pelo povo.
O sapato foi visto pela moça.
O hospital trabalhou sem parar.
O palhaço trabalhou no circo.
O pedreiro trabalhou na chuva.
O médico trabalhou no plantão.
O botão foi achado pelo vovô.
A bolsa foi achada pela babá.
A chave foi achada pela irmã.
O porco foi achado pelo dono.
O dente foi achado pela fada.
A autora conheceu a história.
O cantor conheceu o sucesso.
O artista conheceu o museu.
O pastor conheceu a igreja.
O leitor conheceu o romance.
O animal foi chamado pelo homem.
A pessoa foi chamada pelo rapaz.
O senhor foi chamado pelo amigo.
O macaco foi chamado pelo índio.
A caçula foi chamada pela mamãe.
O colégio gastou a tinta.
A fábrica gastou o material.
O médico gastou o remédio.
A mulher gastou a herança.
A cidade gastou a energia.
O moleque gastou a grana.
A faixa foi recebida pelo time.
A blusa foi recebida pela moça.
A conta foi recebida pelo dono.
A roupa foi recebida pela loja.
A carta foi recebida pelo vovô.
A madrasta dividiu a comida.
O pirata dividiu o tesouro.
A mocinha dividiu o sorvete.

O camponês dividiu o terreno.
A joia foi levada pela filha.
O lixo foi levado pela mamãe.
A cola foi levada pela aluna.
O café foi levado pela prima.
A mesa foi levada pelo rapaz.
A princesa encontrou o castelo.
A menina encontrou a camisa.
O doente encontrou o remédio.
A agência encontrou a cantora.
O ministro encontrou a solução.
A faca foi usada pela irmã.
A casa foi usada pelo dono.
A mesa foi usada pela babá.
O táxi foi usado pelo vovô.
O trem foi usado pelo povo.
A onça morou no mato.
A leoa morou na selva.
O vovô morou na roça.
O vaso foi derrubado pela senhora.
A água foi derrubada pela criança.
O bolo foi derrubado pelo palhaço.
O café foi derrubado pelo capitão.
O copo foi derrubado pelo gatinho.
O filhote nasceu bem forte.
A netinha nasceu em abril.
O cabrito nasceu no sítio.
O patinho nasceu no campo.
A casa foi comprada pelo governo.
O gado foi comprado pela fazenda.
O peru foi comprado pela senhora.
O bote foi comprado pela família.
A bala foi comprada pela criança.
A menina conseguiu a ajuda.
O macaco conseguiu a fruta.
O cavalo conseguiu o capim.
O estudante conseguiu a bolsa.
O mágico conseguiu o balão.
A jovem conseguiu o trabalho.
A sopa foi pedida pelo avô.
O ouro foi pedido pelo rei.
A joia foi pedida pela mãe.
O osso foi pedido pelo cão.
O táxi foi pedido pela tia.

E2: List of sentences for Study II

O vovô morou na roça.
A onça morou no mato.
A notícia foi contada pelo jornal.
O passeio foi contado pelo senhor.
O anúncio foi contado pela pessoa.
O príncipe dividiu o palácio.
A mocinha dividiu o sorvete.
O camponês dividiu o terreno.
O pirata dividiu o tesouro.
A pessoa foi chamada pelo rapaz.
O senhor foi chamado pelo amigo.
A caçula foi chamada pela mamãe.
O esposo encontrou o celular.
A menina encontrou a camisa.
A princesa encontrou o castelo.
O doente encontrou o remédio.
A banana foi comida pelo macaco.
A salada foi comida pela garota.
A cenoura foi comida pelo coelho.
A madrinha ganhou o vestido.
A garotinha ganhou a sandália.
O comprador ganhou a viagem.
A namorada ganhou o cachorro.
O tapete foi colocado pela mulher.
A sacola foi colocada pela titia.
O açúcar foi colocado pela filha.
O frio chegou mais cedo.
O verão chegou com tudo.
O jornal foi lido pela babá.
A página foi lida pelo moço.
O cartaz foi lido pelo povo.
A menina conseguiu a ajuda.
A jovem conseguiu o trabalho.
O mágico conseguiu o balão.
O macaco conseguiu a fruta.
A faixa foi recebida pelo time.
A conta foi recebida pelo dono.
A roupa foi recebida pela loja.
O dente caiu da boca.
O prato caiu da mesa.
A chave caiu da mão.
A moeda caiu do bolso.
A faca foi usada pela irmã.
O táxi foi usado pelo vovô.
O trem foi usado pelo povo.
O moleque subiu o morro.
O morador subiu a escada.
O pano foi lavado pela mamãe.
A meia foi lavada pela filha.
A maçã foi lavada pelo irmão.
O álbum ficou muito lindo.
O jardim ficou muito legal.
O preço ficou muito alto.
A lição foi estudada pelo aluno.
A dança foi estudada pela prima.
O texto foi estudado pelo grupo.
A netinha nasceu em abril.
O cabrito nasceu no sítio.
O patinho nasceu no campo.
O filhote nasceu bem forte.
A bolsa foi achada pela babá.
A chave foi achada pela irmã.
O porco foi achado pelo dono.

E3: List of sentences for Study III

The family moved last month.
The father moved about upstairs.
The prices moved up rapidly.
The person moved in today.
The animal moved very slowly.
The car was left by the officer.
The art was left by the painter.
The box was left by the company.
The key was left by the parents.
The job was left by the workers.
The drivers paid the fine.
The company paid the debt.
The clients paid the bill.
The picture was given by the husband.
The present was given by the friends.
The support was given by the manager.
The product was given by the company.
The example was given by the student.
The staff became very tired.
The smell became much stronger.
The client became annoyed quickly.
The judge became more serious.
The woman became very worried.
The hotel became famous fast.
The heat was felt by the people.
The cold was felt by the family.
The fear was felt by the rabbit.
The care was felt by the friend.
The love was felt by the couple.
The military sat on horses.
The dog sat very still.
The workers sat on chairs.
The army sat in line.
The audience sat very quietly.
The wife was called by the husband.
The girl was called by the parents.
The king was called by the princes.
The lady was called by the teacher.
The bank was called by the company.
The student changed the seat.
The teacher changed the game.
The company changed the food.
The danger was announced by the council.
The change was announced by the college.
The winner was announced by the husband.
The theory was announced by the teacher.
The crisis was announced by the captain.
The driver turned right rapidly.
The chief turned pale again.
The child turned away madly.
The water turned quite cold.
The woman turned around calmly.
The hotel was known by the family.
The music was known by the friend.
The story was known by the school.
The truth was known by the police.
The cause was known by the doctor.
The lunch happened at noon.
The party happened last week.
The visit happened by chance.
The event happened long ago.
The crime happened at night.
The garden was found by the son.
The street was found by the boy.
The office was found by the man.
The branch was found by the dog.
The church was found by the nun.
The gentlemen stood a chance.
The military stood in line.
The police stood very firm.
The students stood on chairs.
The money was received by the winner.
The offer was received by the friend.
The profit was received by the owners.
The paper was received by the school.
The blood was received by the doctor.
The sister closed the book.
The client closed the door.
The police closed the road.
The family closed the shop.
The manager closed the bank.
The dress was made by the women.

The noise was made by the class.
The model was made by the child.
The sound was made by the group.
The story was made by the girls.
The trainer met the player.
The teacher met the pupils.
The brother met the sister.
The speaker met the public.
The readers met the writer.
The farmers met the leader.
The lady was asked by the couple.
The team was asked by the police.
The girl was asked by the doctor.
The army was asked by the leader.
The aunt was asked by the family.
The son carried the card.
The boy carried the book.
The man carried the case.
The book was brought by the student.
The game was brought by the sisters.
The case was brought by the officer.
The data was brought by the teacher.
The food was brought by the brother.
The brother went to church.
The friend went home slowly.
The uncle went very quickly.
The trainer went under ground.
The letter went very far.
The ending was decided by the group.
The colour was decided by the child.
The design was decided by the woman.
The course was decided by the driver.
The result was decided by the judge.
The film appeared last month.
The city appeared in movies.
The star appeared in public.
The king appeared on stage.
The girl appeared very happy.
The office was opened by the company.
The school was opened by the teacher.
The centre was opened by the council.
The league was opened by the captain.
The system was opened by the manager.
The professor believed the student.
The public believed the president.
The mother believed in tradition.
The team believed the leader.
The judge believed the child.
The worker was included by the office.
The couple was included by the church.
The sister was included by the mother.
The auntie was included by the father.
The friend was included by the group.
The church accepted the help.
The client accepted the bill.
The artist accepted the deal.
The author accepted the fact.
The winner accepted the gold.
The agency accepted the cash.
The system was played by the gambler.
The school was played by the college.
The winner was played by the losers.
The sister was played by the brother.
The guitar was played by the student.
The drink looked very nice.
The event looked too boring.
The lunch looked pretty tasty.
The dress looked quite long.
The break was taken by the workers.
The chair was taken by the student.
The drink was taken by the player.
The blood was taken by the doctor.
The money was taken by the company.
The judge worked on cases.
The staff worked so hard.
The doctor worked with patients.
The agent worked with clients.
The guide worked with visitors.
The service was wanted by the school.
The product was wanted by the family.
The victory was wanted by the leader.
The support was wanted by the agency.
The present was wanted by the mother.
The adult broke the phone.
The staff broke the table.
The chief broke the glass.
The woman broke the chair.
The hospital was helped by the church.
The patient was helped by the research.
The military was helped by the doctor.

The business was helped by the leader.
The daughter was helped by the father.
The groups followed the manager.
The pupils followed the teacher.
The couple followed the drivers.
The animal followed the captain.
The bang was heard by the person.
The baby was heard by the parent.
The door was heard by the sister.
The song was heard by the friend.
The bell was heard by the people.
The father told the uncle.
The author told the story.
The bishop told the judge.
The friend told the group.
The cousin told the truth.
The police told the crowd.
The mother told the child.
The book was provided by the professor.
The data was provided by the secretary.
The land was provided by the residents.
The wine was provided by the directors.
The idea was provided by the president.
The son added the drink.
The man added the facts.
The boy added the numbers.
The idea was used by the group.
The land was used by the chief.
The room was used by the staff.
The cash was used by the woman.
The book was used by the girls.
The teacher continued talking loudly.
The train continued without stopping.
The father continued cooking dinner.
The driver continued turning corners.
The sister continued sleeping quietly.
The story continued quite slowly.
The bill was seen by the husband.
The book was seen by the student.
The city was seen by the parents.
The news was seen by the friends.
The fire was seen by the animals.
The problem came to light.
The swimmer came in fifth.
The animals came from nowhere.
The leaders came to terms.
The work was done by the parents.
The show was done by the dancers.
The talk was done by the friends.
The test was done by the student.
The deal was done by the company.
The daughter bought the dress.
The teachers bought the books.
The patient bought the drugs.
The student bought the drink.
The security bought the phone.
The director bought the watch.
The children bought the lunch.
The game was loved by the players.
The girl was loved by the student.
The lady was loved by the manager.
The wife was loved by the husband.
The baby was loved by the parents.
The mother needed the keys.
The writer needed the pens.
The walker needed the shoe.
The student needed the book.
The sister needed the help.
The debt was paid by the couple.
The fine was paid by the doctor.
The bank was paid by the family.
The price was paid by the player.
The bill was paid by the client.
The workers walked far away.
The officer walked away fast.
The hunter walked around quietly.
The pupils walked to school.
The groups walked for hours.
The brother walked home alone.
The talk was begun by the chief.
The game was begun by the group.
The fire was begun by the girls.
The work was begun by the staff.
The task was begun by the child.
The sister fell asleep fast.
The couple fell in love.
The daughter fell down yesterday.
The tooth fell out suddenly.
The leader fell from power.
The bike was lost by the sister.

The book was lost by the cousin.
The coat was lost by the mother.
The belt was lost by the father.
The file was lost by the doctor.
The friends built the castle.
The artist built the museum.
The worker built the school.
The company built the office.
The farmers built the bridge.
The letter was kept by the child.
The record was kept by the police.
The report was kept by the court.
The garden was kept by the staff.
The change was kept by the women.
The staff remembered the family.
The child remembered the murder.
The adult remembered the reason.
The guide remembered the museum.
The judge remembered the client.
The book was started by the author.
The game was started by the player.
The task was started by the leader.
The bike was started by the father.
The race was started by the runner.
The dog got the stick.
The cat got the mouse.
The boy got the drink.
The fan got the ticket.
The son got the medal.
The man got the letter.
The show was expected by the models.
The food was expected by the animal.
The loss was expected by the market.
The test was expected by the driver.
The rain was expected by the father.