University of Groningen

Agreement Processing in Dutch Adults with Dyslexia

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DOI:
10.33612/diss.173346482

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2021

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Salcic, A. (2021). *Agreement Processing in Dutch Adults with Dyslexia*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen. https://doi.org/10.33612/diss.173346482

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Agreement Processing in Dutch Adults with Dyslexia

Aida Salčić

The research reported in this thesis has been carried out under the auspices of the Center for Language and Cognition Groningen (CLCG), the research school of Behavioral and Cognitive Neuroscience (BCN) of the University of Groningen, and the International Doctorate for Experimental Approaches to Language And Brain' (IDEALAB) of the Universities of Groningen (NL), Newcastle (UK), Potsdam (DE) and Macquarie University, Sydney (AU).

Publication of this thesis was financially supported by the Graduate School of Humanities (GSH) of the University of Groningen and by the research school of Behavioral and Cognitive Neuroscience (BCN) of the University of Groningen.

Groningen Dissertations in Linguistics 205

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Cover: Mirza Sadović
Layout: Pentagram.ba
Printed by Ipskamp Printing (NL) - www.ipskampprinting.nl

Agreement Processing in Dutch Adults with Dyslexia

PhD thesis

to obtain the joint degree of PhD at the
University of Groningen, the University of Potsdam,
Macquarie Universityand Newcastle University

on the authority of the
Rector Magnificus of the University of Groningen, Prof. C. Wijmenga,
President of the University of Potsdam, Prof. O. Günther,
Deputy Vice Chancellor of Macquarie University, Prof. S. Bruce
Downton,and Vice Chancellor of Newcastle University, Prof. Ch. Day

and in accordance with
the decision by the College of Deans.

This thesis will be defended in public on

Thursday 24 June 2021 at 9.00 hours

by

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born on 21 April 1988
in Sarajevo, Bosnia and Herzegovina

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In memory of

Senka Salčić, my beloved mother
For always believing in me

ACKNOWLEDGEMENTS

During my PhD, I have often thought (or dreamt) about writing the acknowledgements and what that would really mean. Not only the completion of my doctoral degree, but also a special moment to reflect and thank everyone who has helped during my PhD journey in one way or another. Although it still does not feel real that I am closing this chapter in my life, thanking a large group of people in this section will certainly make it more of a reality.

I would first like to thank my mother, Senka Salčić, whose medical research on stroke patients with aphasia fostered my interest in neurolinguistics and inspired me to pursue research myself. Neither me nor this thesis would have existed without her; I am because she was, in more ways than one. It is therefore that I dedicate this thesis to her.

The work presented in my thesis would not have been possible without my supervisors. First and foremost, I am very grateful to my promotor, Roelien Bastiaanse, who has supervised me since my master's thesis and from whom I have learned a lot. In particular, I would like to thank Roelien for her guidance, expertise, and for inspiring me to always be more critical in my thinking and more precise in my writing. I am also grateful to Lyndsey Nickels, who joined my supervisory team in the last year of my project, but whose thorough feedback has been invaluable in shaping this thesis. I would also like to thank Lyndsey for her kindness, for hosting me at Macquarie University and for making me feel very welcome at the Cognitive Science department. Finally, I am indebted to Srđan Popov, whom I worked with since my master's thesis. I would like to thank Srđan for generously sharing his knowledge, for teaching me about the ins and outs of working with ERPs, for his flexibility, advice, and for all our friendly talks.

Furthermore, I would like to extend my sincere gratitude to my assessment committee: Barbara Höhle, Ben Maassen, Judith Rispens, and Frank Wijnen. Thank you for taking the time to evaluate my work and for your valuable comments.

During my PhD, I had the privilege to be part of a unique PhD program, IDEALAB. I would therefore like to thank the current and former IDEALAB directors: David Howard, Barbara Höhle, Gabriele Miceli, as well as my two supervisors, Roelien and Lyndsey. Thank you for creating such an extraordinary program, for sharing your knowledge, giving helpful feedback at the Winter and Summer Schools, for organizing the IDEALAB training and for the stimulating discussions. I would also like to thank Alice, Anja and Lesley for helping me navigate all the administrative challenges across continents. My IDEALAB PhD cohort (Team Hornets) deserves a special mention for sharing this journey together. In addition to IDEALAB, I am also thankful to my first globe-trotting international family – my EMCL master's cohort – and all the wonderful people in it.

Working on my PhD in Groningen, I was fortunate to be part of the Research School on Behavioral and Cognitive Neuroscience (BCN). I am thankful for all the interesting trainings, courses and events I attended through BCN. In particular, I am grateful to have been able to attend the Neuroanatomy course, one of the most memorable courses in my life. Furthermore, I would like to express my gratitude to Marijke (GSH), Christina (CLCG) and Diana (BCN) for their quick replies, reassurance and help whenever needed.

My project basically consisted of asking a number of people to read or listen to sentences in a lab or online, accompanied by different (mostly reading-related) tasks. Therefore, I am truly grateful to those without whom my project simply would not have existed: my participants. Thank you all for taking the time and being so enthusiastic about participating, learning more about the project, and helping me out.

I have to thank my MA advisor, Nedžad Leko from the Faculty of Philosophy at the University of Sarajevo, for sparking my interest in linguistics. His course on Syntax during my bachelor studies in Sarajevo made me decide to pursue an MA in linguistics and changed the whole trajectory of my career. Had I not taken this course, I certainly wouldn't be where I am today. Thank you, professor, for teaching me so much, for your continued encouragement, for recommending me to apply to the EGG summer schools, and for your always friendly demeanor and interest in my research and experiences abroad.

In Groningen, I had the distinct pleasure to be part of great research community. Therefore, I am thankful to the current and former members of the Neurolinguistics group (not an exhaustive list): Adrià, Annie, Atilla, Ben, Camila, Dörte, Effy, Ellie, Frank, Irene, Jakolien, Jidde, Juliana, Kaimook, Liset, Miren, Nat, Nermina, Nienke, Pauline, Roel, Sana, Seçkin, Solveig, Suzan, Teja, Toivo, Vânia, Wim, Weng, and Yulia. Thank you for your continued feedback on my work, and for fostering such an enjoyable and stimulating work atmosphere. And thank you, Juliana, Annie, Assunta, Jidde, Toivo, Irene, Pauline, Camila, Teja, Mara, Yulia, for all the borrels, picnics, barbecues and impromptu coffee/tea breaks.

Several members of the Neurolinguistics group deserve a special mention for their help with my project. I am very happy to have had a PhD colleague who was also doing research on adults with dyslexia. Thank you, Liset, for all your help with recruiting participants, sharing participants/data, our discussions on dyslexia, for being my conference buddy, and most importantly, for your friendship. My sincere gratitude also goes to Seçkin. Although he was not officially a part of my supervisory team, Seçkin stepped in at a time when I had to pivot to self-paced reading when the pandemic suddenly hit. Thank you for teaching me how to set up an SPR experiment, for your help with the data analysis, for always finding the time, as well as for your optimism. I am also grateful to Wim for helping me choose the behavioral tests used in this thesis and for our discussions about dyslexia and my project.

Sharing "the best office in town" was a breeze with some incredible officemates over the years. Thank you, Juliana, Jidde, Irene, Liset, Jakolien, Nermina, and Weng, for the vibrant atmosphere. Thank you, Jidde, Liset and Irene for always patiently proofreading my emails to participants in Dutch. And many thanks to Irene, Liset and Pauline for correcting my translation of the Dutch summary in the thesis. I am grateful to Liset, Suzan and Sjors for their help with participant recruitment, and to Juliana, Atilla, Irene, Marjolein, Almut, Ilse, Iris, Michelle, and Frank for their help with the EEG data collection.

I also had the pleasure of supervising three interns in the EEG lab: Ilse, Iris and Michelle. I have immensely enjoyed working with the three of you! Thank you for your interest in my project and for your help with creating the stimuli for the SPR study. Ilse and Iris, thank you for deciding to write your MA theses with me as your supervisor and for your help with testing participants and scoring behavioral data for some of the participants in the final experiment. I am also indebted to Claire for her help with scoring.

During my PhD, I spent 6 months at the Cognitive Science department at Macquarie University in Sydney. To all the CogSci members: thank you for creating such a friendly work environment. The transition from Groningen to Macquarie was so seamless, both professionally and personally, that it (almost) made me rethink the saying: "Er gaat niets boven Groningen". I've truly enjoyed my time in Sydney and there are a number of lovely people who are responsible for that: Valentina, Leonie, Ana, Hannah, Andrea, Diane, Irene, Inga, and others. I can't wait to be back, but in the meantime, thank you for all the lunches, coffee/tea breaks, 'barbies', hikes, dinners, as well as all the laughs and all the fun in between. And to my dear Vale, as amazing as my Australian adventure was, us meeting at Macquarie and becoming such close friends is one of the best parts of it! I am so grateful for your friendship, moral support and encouragement since then. I couldn't have picked a better person to share all the ups and downs of finishing the PhD at the same exact time.

Doing a PhD is hard, so I am grateful to all the friends who have made this journey easier. I owe my gratitude to my PhD friends Juliana, Annie, and Assunta for their friendship, unwavering support, an unlimited number of puns, as well as always bringing their A-game. Ju, my *irmã*, thanks for so many things! Thanks for always being there, for sharing all the good and bad times, for the *pura vida,* and now for being my paranymph. Annie, I'm happy we met on the first day

of EMCL and became good friends quickly. Thanks for your support over the years, out shared sense of humor, all the pub quizzes, travels, for growing and laughing together. And Assunta, thanks for your thoughtfulness, encouragement, our Skype office hours, and the sweetest greeting cards that always cheer me up.

Living abroad does have its perks. One of them is having friends in all corners of the world: Jan, Jelena, Marco, Jasmin, Ena, Saša, Nermina, Bernat, Ina, Ana, Nenad, Maja, Marjolein, Flo, and others. Special thanks go to Jelena and Saša, as well as Marco and Jasmin for always being my home-away-from-home, whether in Groningen/Amsterdam or Rotterdam/Schiedam.

And a giant 'thank you' to the friends I've known the longest and who've always been in my corner – my friends from Sarajevo: Dženana, Niđara, Alma, Sanja Š., Jovan, Dženan, and Mirza. My dear Dženi, I am so honored to have you as my best friend and now as my paranymph! It's crazy to think that we've grown together so much over the past 25 years and still remain inseparable. Our friendship means so much to me that a simple 'thank you' is really not enough, but still: hvala! Dear Niđara, thank you for always knowing what to say, for your wisdom, sharing the same sense of humor, for always taking good care of my heart and for healing me with food whenever I came to visit in Marseille/Lucca broken after conferences. Nura is so lucky to have you! My dear Alma, thank you for your support and kindness, for laughs and fun, for sharing all the highs and lows – all the way from our late-night studying sessions and phone calls to now both finishing our PhD's! To Sanja Š. for all the adventures we've had; to Dženo for all the walks, visits, food and deep talks. To Jovan for all his help over the years, for our talks, sharing music, books and finally, guitars in Canada. I am also grateful to both you and Radenka for hosting me in Canada for the SSSR conference. And thank you, Mirza, for becoming such an integral part of my thesis by designing the thesis cover and for making my cover idea the most wonderful reality. It's genuinely a piece of art.

I am also grateful to Shady, for too much to count, but I'll still give it a shot: thank you for all your love, support, patience, care, for believing in me when I didn't, and for some statistics magic when nothing worked. Since the last year of my PhD coincidentally took place during a global pandemic, Shady has been the best lockdown company and kept me sane during this time (though I'm not sure if he'd say the same about me during the writing stage!). Shady, you made this PhD journey much more enjoyable and I'm looking forward to all our new adventures!

And finally, a thank you to my loving family: my mother Senka and father Dragan, my sister Sanja, my grandparents Munirka and Mustafa, my uncles Ahmed and Sead, as well as Jasmina, Armin, Amna, and others. Sanjo, I am grateful to have you as my big sister, for always motivating me and being there

whatever happens. Hvala ti što si mi najbliža osoba na svijetu. Voli te puno tvoj Ico. To Amna, for always bringing a smile to my face. To my uncle Ahmed, who is like a second father to me and who has taught me so much in life. Hvala ti na svemu, Aki. Puno mi znači što si uvijek bio uz nas i što si nas uvijek volio kao svoju djecu. Mimo i Mujo, vaš trag je u svemu što sam do sada postigla. Ovaj uspjeh ne bi bio moguć bez vas i vaše podrške. And a special thank you to my grandma Mima, whom I always had a special bond with, who is one of the the most intensely curious and creative people I've met and is my role model in so many things.

And finally, to my parents: Dragan and Senka. I am grateful to you for more than can fit into this thesis. Thank you for your never-ending support, unconditional love, for always believing in me, and investing so much in our education. Volim vas puno! Mama, I'd wish nothing more than you being here and being able to hold this thesis in your hands. But I know how proud of me you were and I know you'd be very proud of me today. Nedostaješ neizmjerno.

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CHAPTER 1

General Introduction

"Our understanding of dyslexia is a work in progress and will continue to be just that."
(Lyon et al., 2003, p. 10)

1. Introduction

According to the reading researcher Maryanne Wolf, "we were never born to read" (Wolf, p. 3). Reading is a recent cultural invention (Dehaene, 2009): the oldest writing systems emerged less than 6,000 years ago (Huettig et al., 2018). Evolutionarily speaking, this represents too short a time for our brain to develop neural pathways devoted exclusively for reading. Instead, when we learn to read, our brain needs to adapt and reorganize the existing brain circuitry for this new activity, which becomes automatized through considerable practice in only a few short years (Dehaene, 2009; Huettig et al., 2018). While reading is acquired relatively quickly by most children, some children inexplicably fail to acquire fluent and accurate reading abilities, despite sufficient educational and environmental support to do so. These reading difficulties typically persist into adulthood, and children and adults who experience them are frequently diagnosed with "dyslexia". Developmental dyslexia (henceforth: dyslexia) is an impairment in reading and/or writing, characterized by difficulties in word recognition (low accuracy and/or speed), poor word decoding (i.e., of letters into sounds) and/or poor spelling skills (American Psychiatric Association, 2013; Stichting Dyslexie Nederland – SDN et al., 2016).

Regardless of differences in orthographies, dyslexia is observed across different languages and writing systems (Peterson & Pennington, 2012). The estimates of prevalence depend on the criteria used for defining dyslexia, as well as the orthography in question (Peterson & Pennington, 2012; Ziegler & Goswami, 2005). Dyslexia affects approximately 3-10% of the general population (Miles, 2004; Peterson & Pennington, 2012), although some estimates place its prevalence as high as 17-20% of the population (Ferrer et al., 2015; Sprenger-Charolles et al., 2016).

Ever since the early descriptions of dyslexia in the 19th century (Berlin, 1887; Hinshelwood, 1896), researchers have been trying to uncover the cause of dyslexia, or "the Holy Grail: the single cognitive deficit that is necessary and sufficient to cause all behavioral characteristics of the disorder" (van Bergen et al., 2014, p. 1). Although the etiology of dyslexia is complex and cannot be sufficiently captured by 'reductionist' single-deficit models (Astle & Fletcher-Watson, 2020), the most prominent cognitive theory of dyslexia remains the *phonological deficit theory* (e.g., Snowling, 2000), which links the underlying impairment in dyslexia to problems in the domain of phonology. Consequently, the majority of previous research on dyslexia has focused extensively on phonological skills, whereas high-level linguistic domains (e.g., semantics and morphosyntax) have received less attention. However, a considerable number of individuals with dyslexia also exhibits non-phonological impairments, including those in the domain of morphology and syntax (Callens et al., 2012). Furthermore, much less is known about morphosyntactic processing in adults with dyslexia compared to children with dyslexia. Engelhardt (2020) argues that research on dyslexia, in particular on adults with dyslexia and their syntactic processing (i.e., sentence-level language comprehension), has largely been ignored in the field of psycholinguistics. Meanwhile, individuals with dyslexia experience lifelong difficulties with efficient reading and "spend a great deal more of their life dealing with 'adult-type' symptoms of dyslexia" (Engelhardt, 2020, p. 2). Hence, it is critical to understand dyslexia across the lifespan.

In order to shed more light on non-phonological skills in dyslexia, this thesis focuses on morphosyntactic processing, or more precisely, on agreement violation processing in Dutch adults with dyslexia. Thus, we explore differences in the processing of grammatical and ungrammatical sentences that only differ in the presence/absence of a violation of morphosyntactic information (e.g., grammatical: *'She$_{SG}$ loves$_{SG}$ penguins.';* ungrammatical: *'*She$_{SG}$ love$_{PL}$ penguins.'*). In particular, this thesis examines the unique contribution of several methodological and linguistic factors to agreement violation processing in dyslexia. To that end, we present studies on the different psycholinguistic processes involved in gender and number disagreement on the one hand (Chapters 2 and 3) and subject-verb disagreement on the other (Chapter 4). Additionally, we investigate the role of presentation modality (reading vs. listening), and the influence of linear distance as a measure of working memory on agreement violation processing. In adults, potential morphosyntactic processing difficulties are usually subtle and often only visible on online (e.g., event-related brain potentials – ERPs), rather than on behavioral tasks (e.g., Rispens et al., 2006). Since we were principally interested in the temporal aspect of agreement violation processing in dyslexia, we used a combination of ERPs and self-paced reading (SPR) as our experimental methods.

In the following sections of this Introduction, we provide a brief overview of the various definitions and causal theories of dyslexia, as well as the characteristics of adults with dyslexia. This is followed by a description of the techniques used (ERPs and SPR) and a summary of previous research on agreement violation processing with ERPs, with a particular focus on dyslexia. We also provide linguistic background on the stimuli used in the current thesis: gender and number disagreement on the one hand, and subject-verb disagreement on the other. Finally, the research questions and hypotheses are formulated, followed by an outline of the structure of the thesis.

1.1 Definition(s) of Dyslexia

The definition of dyslexia has changed over the years. In 1994, the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 1994) characterized dyslexia as a reading disorder, in which reading skills are considerably below those expected based on a person's intelligence, education, and chronological age. In this definition, dyslexia was defined in terms of a discrepancy score: the difference between reading achievement and achievement predicted based on intelligence scores (Shaywitz et al., 1992). However, nowadays the majority of researchers and practitioners recognize that the discrepancy between reading achievement and IQ or age should not be the defining characteristic of dyslexia, since dyslexia exists across a whole continuum of intellectual abilities (Rose, 2009). The DSM-IV (American Psychiatric Association, 1994) definition of dyslexia has also been criticized for only providing exclusion criteria (i.e., focusing on what dyslexia is not), without many inclusion criteria for diagnosing dyslexia (Fletcher, 2009). In order to remedy this, a new definition of dyslexia was proposed in DSM-5 (American Psychiatric Association, 2013). This new definition includes not only reading, but also spelling skills, and provides specific inclusion criteria for a dyslexia diagnosis. Thus, DSM-5 characterizes dyslexia as:

> *"[a] pattern of learning difficulties characterized by problems with accurate and/or fluent word recognition, poor decoding, and poor spelling abilities"* (American Psychiatric Association, 2013, p. 67)

One of the most widely recognized definitions of dyslexia is the one by Lyon et al. (2003), adopted by the International Dyslexia Association (IDA), which states the following:

> *"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 problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge."*
>
> (Lyon et al., 2003, p. 2)

Apart from recognizing dyslexia as a specific reading impairment at the word level, this definition avoids oversimplification and even emphasizes the heterogeneity of dyslexia by including some of its secondary consequences.

However, all definitions of dyslexia agree that it is an impairment at level of single words (Stanovich, 1991; Vellutino et al., 2004) and secondary characteristics are not diagnostic markers of dyslexia (Rose et al., 2009).

Furthermore, dyslexia exists on a continuum of reading abilities and as such is a continuous, not a discrete, impairment. In other words, there is no natural cut-off or categorical boundary for distinguishing the literacy skills of individuals with and without dyslexia (Peterson & Pennington, 2015; Rose et al., 2009; Shaywitz et al., 1992). Similarly, Shaywitz et al. (1992) proposed that dyslexia might represent the lower tail of the normal distribution of reading ability. Due to its heterogeneity, there is no dyslexia-specific cognitive profile and some researchers argue that the diagnosis of dyslexia should include assessments which identify both domains of strengths and weaknesses (Everatt et al., 2008).

The definition of dyslexia used in this thesis is that of the Dutch Dyslexia Association (Stichting Dyslexie Nederland – SDN). SDN et al. (2016) defines dyslexia as a specific learning impairment characterized by persistent problems in reading and/or spelling accurately and fluently at the word level, which is not a consequence of environmental factors and/or neurological, physical or general intellectual disability. According to this definition, a dyslexia diagnosis should include the following three criteria: 1. Impairment in reading and/or spelling at the word level; 2. Persistence: the reading and/or spelling problems persist despite formal education, training or writing remediation; and 3. Exclusion: no alternative explanations are available for the reading and/or spelling problems. The persistence of a reading impairment is a particularly important criterion for advanced readers with dyslexia, who are the population under investigation in this thesis.

For the purpose of the experiments reported in this thesis, participants with dyslexia were required to have a formal diagnosis of dyslexia that was valid at the time of testing. The dyslexia diagnosis was confirmed using a questionnaire (particularly focusing on Criteria 2 and 3) and the use of selected behavioral tasks to address the first criterion: single word reading, pseudo-word reading, and spelling to dictation. For participants without dyslexia, we either confirmed that they did not meet the cut-off for dyslexia on a diagnostic test or that they self-reported no (history) of reading or language difficulties. Previous research provides evidence supporting the use of self-reports for typical reading skills (e.g., Nicolson & Fawcett, 1997). Self-assessments of perceived difficulties with reading have also been found to be a valid and reliable measurement of actual reading difficulties, including dyslexia, in adults (e.g., Felton et al., 1990; Snowling et al., 2012; Tamboer & Vorst, 2015).

1.2 Etiology of Dyslexia

A causal modelling framework (Frith, 2002; Jackson & Coltheart, 2001; Morton & Frith, 1995) has been developed to explain the complex etiology of developmental language impairments, including dyslexia. According to this framework, the causal model of dyslexia includes three levels of description: biological (genetic and neurological), cognitive and behavioral, which all interact with environmental factors (Frith, 2002; Morton & Frith, 1995).

There is a strong genetic component in dyslexia (see Carrion-Castillo et al., 2013; Fisher & DeFries, 2002; for an overview). Indeed, dyslexia is reported in approximately 45% of children who have a first degree relative with dyslexia (Snowling & Melby-Lervåg, 2016). Twin studies reveal a prevalence of 68% in monozygotic twins and 38% in dizygotic twins (DeFries & Alarcón, 1996). Molecular genetic analyses have identified several candidate genes associated with dyslexia (e.g., Taipale et al., 2003), but the results have not been widely replicated (e.g., Becker et al., 2014). At the level of neurobiology, structural and functional brain differences have been observed between individuals with and without dyslexia. Neurobiological differences between children with and without a familial risk of dyslexia have been argued to emerge long before the acquisition of reading and writing skills, suggesting a strong biological basis for dyslexia (e.g., Guttorm et al., 2003). Furthermore, dyslexia has been associated with reduced brain activation and functional connectivity between the hemispheres and different brain areas (e.g., Finn et al., 2014; Horwitz et al., 1998; Pugh et al., 2000). Other studies found abnormalities in tempo-parietal white matter and gray matter structures, associated with reading processes, in children with (a familial risk of) dyslexia (e.g., Richlan et al., 2009; Steinbrink et al., 2008; Vanderauwera et al., 2017). However, both genetic and environmental factors contribute to reading achievement (Shaywitz & Shaywitz, 2005; Van Bergen et al., 2014). Thus, dyslexia is thought to be caused by a number of biological and environmental risk factors (e.g., socioeconomic status, home literacy environment and child health risks; Dilnot et al., 2017), as well as their interaction (Peterson & Pennington, 2015).

The etiology of dyslexia is complex and various theories have long sought to pinpoint the underlying cause of the observed impairments in dyslexia. Due to the existence of heterogenous impairments, dyslexia is nowadays typically seen as having multifactorial etiology in the prism of the *multiple deficit model* (MDM; Pennington, 2006; Pennington & Snowling, 2009). However, single-deficit cognitive models of dyslexia remain popular and the cognitive theory that has gained the most ground is the previously-mentioned *phonological deficit theory* (e.g., Snowling, 2000). This theory links the underlying impairment in dyslexia to a deficit in the perception, storage, manipulation and retrieval of speech sounds (e.g., Ramus et al., 2003; Snowling, 1981, 2000; Vellutino et al., 2004; see Melby-Lervåg et al., 2012, for a meta-analysis). However, phonological deficits cannot fully account for the heterogeneity of dyslexia (e.g., Castles & Friedmann, 2014), since not all individuals with dyslexia exhibit a phonological deficit (e.g., Ramus et al., 2013) and not all individuals with a phonological deficit are diagnosed with dyslexia (e.g., Van Bergen et al., 2014). It is also important to note that the proposed theories often do not distinguish between cause and effect: what is seen as the underlying cause of dyslexia (e.g., phonological deficit) might be merely a symptom of the impairment.

1.3 Adults with Dyslexia

Dyslexia persists into adulthood (e.g., Lyon et al., 2003). Generally speaking, "a person who is diagnosed as dyslexic remains diagnosably dyslexic all his/her life" (Lefly & Pennington, 1991, p. 143). However, some individuals with dyslexia are referred to as "compensated", since they are able to compensate for their reading problems in some way, resulting in normal reading and spelling scores (e.g., Law et al., 2015).

Similar to children with dyslexia, adults with dyslexia also exhibit slow reading (i.e., slow processing speed) and, often, phonological impairments (e.g., Callens et al., 2012; Martin et al., 2010; Swanson & Hsieh, 2009). Regarding the secondary characteristics of dyslexia, adults with dyslexia self-report executive function problems that affect their everyday life and self-efficacy (e.g., problems with working memory, planning, organization and task monitoring) more frequently than adults without dyslexia (Smith-Spark et al., 2016). Adults with dyslexia are also more prone to problems related to their emotional and psychological wellbeing, including mental health problems (e.g., anxiety), lower self-esteem, and attentional problems than students without dyslexia (e.g., Carroll & Iles, 2006; Ghisi et al., 2016).

The number of students with dyslexia entering higher education is on the rise due to better assessment and remediation (Callens et al., 2012). In the UK, approximately 3.2% of university students enter higher education institutions with a diagnosis of dyslexia, but up to 43% of students with dyslexia only receive a formal diagnosis during their studies (Warmington et al., 2013). The few systematic studies on cognitive profiles of university students with dyslexia revealed that both English-speaking and Dutch-speaking students with dyslexia exhibited poorer performance relative to their peers without dyslexia on measures of language and cognition. These included word reading, pseudo-word reading, spelling, rapid naming, verbal memory, phonological processing, and arithmetic

(Swanson & Hsieh, 2009), as well as problems with the speed of writing (Callens et al., 2012). Other studies on university students with dyslexia found that their reading comprehension was unimpaired, especially when provided with sufficient time (Deacon et al., 2012; Parrila et al., 2007; but see Callens et al., 2012). The above results were echoed in a meta-analysis of reading-related skills in adults with dyslexia in different orthographies (Reis et al., 2020). This study revealed that adults with dyslexia exhibited poorer performance than adults with dyslexia on all reading- and writing-related tasks (especially word and pseudo-word reading), which were more prominent in speed measures, while reading comprehension was intact. Additionally, phonological deficits emerged as a relatively minor problem in adults with dyslexia, particularly in transparent orthographies.

1.4 Theories of Morphosyntactic Processing in Dyslexia

The processing of (morpho)syntax has been sporadically studied in children and adults with dyslexia, and different theories have been proposed regarding the nature of the observed morphosyntactic limitations.

The ***phonological processing limitation hypothesis*** by Shankweiler et al. (1992) is an example of a theory which attributes morphosyntactic processing limitations in dyslexia to problems at the phonological level. According to this hypothesis, linguistic information is first processed at the phonological level, hence any deficits at this level prohibit the linguistic material from being transferred to working memory (WM) and later to higher-level linguistic systems responsible for semantic and syntactic processing. Thus, impaired phonological processing creates a processing bottleneck for higher-order morphosyntactic skills, but these morphosyntactic skills themselves are relatively intact. A phonological processing deficit has been linked to difficulties in morphosyntactic processing in a number of studies (e.g., Casalis et al., 2013; Joanisse et al., 2000; Leikin & Assayag-Bouskila, 2004; Rispens et al., 2004; Robertson et al., 2013; but see, e.g., Cantiani et al., 2013b). Problems in the phonological domains of STM and WM are well-documented in both children and adults with dyslexia (e.g., Jeffries & Everatt, 2004; Smith-Spark & Fisk, 2007). As mentioned before, morphosyntactic processing crucially relies on the temporary storage of the linguistic material (i.e., the phonological code) by STM, which further transfers it to WM for processing. If the linguistic material is not properly stored, especially in the case of complex syntactic structures, then sentence processing becomes more challenging. Several studies have linked WM constraints to limitations in sentence processing in individuals with dyslexia in studies involving production (e.g., Shankweiler & Crain, 1986; Wiseheart & Altmann, 2018), spoken comprehension (e.g., Robertson & Joanisse, 2010; Shankweiler & Crain, 1986), and written comprehension (e.g., Stella & Engelhardt, 2019; Wiseheart et al., 2009). Phonological STM (measured with a non-word repetition task) has been found to be correlated with the performance of children with dyslexia on different tasks tapping into morphosyntactic skills (e.g., Bar-Shalom et al., 1993; Delage & Durrleman, 2018; Jiménez et al., 2004; Rispens & Been, 2007). Lastly, multiple studies have reported that when WM functioning was statistically controlled, group differences disappeared and individuals with and without dyslexia then displayed a relatively comparable performance on morphosyntactic tasks (e.g., Roberston & Joanisse, 2010; Wiseheart & Altmann, 2018; Wiseheart et al., 2009).

Another account of morphosyntactic difficulties in dyslexia has been embodied by the ***structural lag hypothesis***, which postulates the existence of a morphosyntactic deficit independent from an underlying phonological impairment in individuals with dyslexia (e.g., Byrne, 1981; Catts et al., 1999; Gallagher et al., 2000; Stein et al., 1984; Waltzman & Cairns, 2000). A longitudinal study by Catts and colleagues (1999) found that oral language skills (including grammar, vocabulary and narrative scores) contribute independently to reading skills. Thus, according to Catts et al. (1999), grammatical skills in dyslexia are not influenced by a phonological processing deficit, but both grammatical and phonological skills contribute independently to reading acquisition in dyslexia. According to Byrne (1981), this morphosyntactic deficit stems from individuals with dyslexia "operating at a less mature linguistic level" (Byrne, 1981, p. 209). Finally, several recent studies found evidence for the existence of a specific morphological or morphosyntactic processing impairment in dyslexia, which is independent to an underlying phonological or WM deficit (e.g., Antón-Méndez et al., 2019; Leikin & Hagit, 2006).

An additional explanation for morphosyntactic processing problems in dyslexia is that these difficulties are due to a **delay in grammatical acquisition**, caused by reduced exposure to written text in individuals with dyslexia compared to typical readers. In order to test this hypothesis, several authors investigated the production and comprehension of morphosyntax in preschool children with a risk of developing dyslexia, who had not started their formal reading acquisition and had not yet demonstrated a reading impairment compared to children who were not at risk (e.g., Lyytinen et al, 2001; Rispens, 2004; Scarborough, 1990; Van Alphen et al., 2004; Wilsenach, 2006). Since both groups had no written text exposure, reduced exposure in the at-risk children could not explain the observed differences in the production and comprehension of (complex) syntactic structures, such as passives. Furthermore, the hypothesis of a delay in acquisition of morphosyntactic processing implies that children with dyslexia should be able to catch up with their peers. Consequently, the persistent morphosyntactic difficulties observed in adults with dyslexia (e.g., Cantiani et al., 2013a, 2013b) and university students with dyslexia (e.g., Raveh & Schiff, 2008; Rispens et al., 2006; Wiseheart & Altmann, 2018; Wiseheart et al., 2009) provide further evidence against the maturational delay hypothesis. These results lend further support against the view that a delay in the acquisition of grammatical constructions, caused by reduced reading experience, is the source of the observed morphosyntactic problems in individuals with dyslexia.

1.5 Event-Related Brain Potentials (ERPs) and Agreement Violation Processing

In this section, we describe one of the focuses of this thesis, the major event-related brain potential (ERP) components in agreement violation processing, as well as the previous research on these components in dyslexia. ERPs represent brain responses time-locked to a particular stimulus observable in a continuous electroencephalogram (EEG) signal. The recording of the brain's electrical activity is conducted via electrodes placed on the scalp capturing the small neural changes in voltage as a response to the environment or a given stimulus. The changes in voltage reflecting the underlying electrical signal are relatively small and can be measured (in microvolts) over milliseconds on the scalp (for a more a detailed overview of ERPs, see Luck, 2005).

In sentence processing research, ERPs have typically been used in two major types of paradigms: the violation paradigm and the oddball paradigm. A violation (or violation-of-expectation) paradigm is one in which a stimulus (e.g., a word) that is presented auditorily or visually is different from what the listener or reader expects based on previous knowledge of language or the world. In linguistic research, such a paradigm is used in both reading and listening tasks and is employed in the fields of syntax, semantics, phonology, or the interface of these sub-fields. In the oddball paradigm, a stimulus (e.g., a word, syllable, or sound) is typically presented auditorily in a sequence that is interspersed with an occasional dissimilar stimulus. This different (i.e., oddball) stimulus is the one that elicits the effect.

ERPs offer a unique insight into the detailed online time course of language processing. They can help us see how the entire operation of language processing unravels in real time by enabling us to pinpoint when exactly a stimulus causes a certain effect and how long it lasts. ERPs vary in terms of the following elements: topography (scalp distribution), latency (time course of the component; in milliseconds), polarity (positive- or negative-going deflection), amplitude (component strength; in microvolts), as well as in the functional description of the underlying cognitive processes they are thought to represent (e.g., Key et al., 2005; Luck, 2005).

Much of the early electrophysiological research was dedicated to discovering and disentangling the nature of different ERP components and thus far, the following major ERP components associated with agreement violation processing have been identified: the N400, the Left Anterior Negativity (the LAN), and the P600. Recently, however, the idea that there is a one-to-one mapping between the ERP components and a distinct linguistic level (e.g., the N400 – semantics, the P600 – morphosyntax) has fallen out of favor. Instead, different underlying functions have been associated with a single component (e.g., semantic P600: Brouwer et al., 2012; Kim & Osterhout, 2005; see Sassenhagen et al., 2014 for more information). Nevertheless, in order to maintain consistency with previous literature on agreement violation processing using ERPs, we will use the traditional classification of the three above-mentioned ERP components identified in agreement processing. Thus, in our description of the ERP components below, we follow Friederici's (2002) auditory sentence processing model (see sections 1.6.2 and 1.6.3 on the LAN and the P600, respectively) and summarized in Molinaro et al.'s (2011) review.

1.6 Event-Related Brain Potentials (ERPs) in Dyslexia

In general, previous research has reported temporal, topographic and/or qualitative differences between individuals with and without dyslexia using ERPs, including anomalous ERP activation in individuals with dyslexia. For instance, studies on the mismatch negativity (MMN), an ERP component associated with the automatic discrimination of deviant ('oddball') stimuli in a sequence of repetitive auditory stimuli, consistently demonstrate a difference between groups of participants without dyslexia and groups of participants with (a familial risk of) dyslexia, indicating an impairment in auditory temporal processing in individuals with dyslexia (see Bishop, 2007, for a review). Furthermore, Van Setten et al. (2016) found an anomalous N1 ERP component in Dutch higher education students with dyslexia suggesting that they exhibited a deficit in print tuning (i.e., an early sensitivity to print). In a study by Horowitz-Kraus and Breznitz (2011), adults with and without dyslexia were required to read (non-)words and sentences and perform a lexical decision task in Hebrew. They found a difference in the elicitation of error-related negativity (ERN/Ne: an ERP component evoked following erroneous responses) between the groups. In adults with dyslexia, the amplitude of the ERN/Ne was smaller, which may denote lower activation and a general difficulty in detecting errors in words and sentences in Hebrew compared to typical readers (Horowitz-Kraus & Breznitz, 2011).

In the section that follows, we will describe the three main ERP components identified in research on agreement violation processing in typical readers (i.e., the N400, the LAN, and the P600), as well as the studies that reported these components in research on children and adults with dyslexia.

1.6.1 N400

The N400 is a negative-going waveform that typically occurs in centro-parietal scalp sites between 300 and 500 ms post-stimulus onset, with a peak at approximately 400 ms (hence the name: 'N' stands for negativity and 400 for the peak of the component in ms). Since its description by Kutas and Hillyard (1980), the exact interpretation of this ERP component has generated ample debate over the years (see Kutas & Federmeier, 2011; Lau et al., 2008, for an overview). In sentence comprehension, the N400 has typically been elicited by lexical-semantic violations in response to a semantically incongruent final word: 'He spread the warm bread with socks.' (vs 'butter'; Kutas & Hillyard, 1980). Additionally, the N400 has been taken to represent an index of semantic evaluation of words, since it is elicited in semantic priming/lexical decision tasks (e.g., Deacon et al., 2000; Kutas & Hillyard, 1980). According to Kutas and Federmeier (2000), the amplitude of the N400 is influenced by the difficulty of accessing information stored in semantic memory. Evidence for this claim comes from studies that have reported a larger N400 amplitude in response to non-words than words (e.g., Chwilla et al., 1995; Holcomb, 1988; Sebastian-Galles et al., 2006).

1.6.1.1 N400 in Dyslexia Research

A number of tasks have been used to elicit the N400 in studies on dyslexia, including: reading or listening to semantically incongruent sentence endings, semantic judgement task, word recognition or categorization task, and lexical decision task. While some studies reported no difference in the elicitation of the N400 between individuals with and without dyslexia (e.g., Lovrich et al., 1997; Sabisch et al., 2006), others have found a difference between the groups (e.g., Brandeis et al., 1994; Hasko et al., 2014).

The auditorily presented electrophysiological studies that have found no difference in the elicitation of N400 between individuals with and without dyslexia interpreted it as lack of evidence for an impairment in semantic processing in dyslexia (e.g., Lovrich et al., 1997; Sabisch et al., 2006). Most of these studies used a typical violation paradigm containing sentences with congruent and incongruent endings (which usually elicit the N400). As an illustration, Sabisch et al. (2006) show that the amplitude of the N400 in response to listening sentences with a semantic violation (e.g., *Der Vulkan wurde gegessen:* '*The volcano was eaten'*) was comparable between German children with and without dyslexia. The two studies that have investigated semantic processing in visually presented stimuli in dyslexia also observed a comparable N400 effect in individuals with and without dyslexia on different tasks (repetition memory: Rüsseler, et al., 2003; priming: Silva-Pereyra et al., 2003).

Other studies have reported aberrant N400 responses to visually and auditorily presented stimuli in individuals with dyslexia compared to individuals without dyslexia. They predominantly found a delayed effect, reduced amplitude or longer persistence of the N400 (e.g., Brandeis et al., 1994; Hasko et al., 2014; Helenius et al., 1999, 2002; Robichon et al., 2002; Rüsseler, et al., 2007; Schulz et al., 2008). However, some studies have found a larger N400 amplitude for individuals with dyslexia compared to individuals without dyslexia (e.g., listening: Neville et al., 1993; reading: Robichon et al., 2002). Most of these studies interpret anomalies in the N400 elicitation in individuals with dyslexia as evidence for a semantic processing impairment (e.g., Rüsseler, et al., 2007), or, more specifically, a difficulty with the semantic integration of words within a sentential context (Robichon et al., 2002). However, other authors conclude that individuals with dyslexia might rely on context rather than single words for comprehension, or use a different mechanism for processing the meaning of words, as indicated by a different neural pattern (e.g., Brandeis et al., 1994; Neville et al., 1993).

In agreement violation processing (i.e., listening to sentences containing subject-verb disagreement in Italian), an 'N400-like' component was reported by Cantiani and colleagues (2013a, 2015) for individuals with dyslexia compared to their peers without dyslexia. In adults with dyslexia, Cantiani et al. (2013a) reported a P600 for both groups and an additional 'N400-like' component only for the group with dyslexia in the same paradigm. In Italian children with dyslexia, Cantiani et al. (2015) reported a different ERP component (a broadly distributed Negativity, interpreted as the N400) compared to a P600 elicited for both typically developing children and children with combined dyslexia and developmental language disorder (DLD) in response to subject-verb disagreement. This 'N400-like' component in both children and adults with dyslexia was interpreted as a lexical-semantic strategy that serves as compensation for the difficulties in constructing or applying the rules of inflectional morphology.

The inconsistencies in the N400 elicitation in studies on dyslexia could be attributed to a number of factors, including population under investigation (children vs. adults), stimuli and tasks used, as well as the modality of presentation (Hasko et al., 2013).

1.6.2 Left Anterior Negativity (LAN)

The Left Anterior Negativity (LAN) is a negative-going deflection with a left-lateralized anterior distribution, as the name suggests. Friederici et al. (1993) related this component with morphosyntactic processing and posited that it can be associated with two different latencies. An early manifestation of the component then occurs at approximately 100 ms as an Early Left Anterior Negativity (eLAN,) and a later one (LAN) occurs with an onset of roughly 300 ms. The eLAN has been reported as the first-phase of a ‘syntax-first’ electrophysiological model of auditory sentence processing (Friederici, 2002), in which the parser first builds a syntactic local phrase structure and only then proceeds to integrate semantic information. It was proposed that the eLAN occurs between 100 ms and 300 ms, as a response to unexpected syntactic word categories that interfere with initial phrase structure building (Friederici et al., 1993). During the second phase of phrase-structure building (300-500 ms), both automatic morphosyntactic processing (the LAN) and lexical-semantic integration (the N400) take place. In this phase, the LAN occurs as a response to morphosyntactic violations within rapid, automatic processing. It can thus be elicited by, amongst other things, phrase structure incongruencies such as: ‘*Max’s of proof’ vs. ‘Max’s proof’ (example from Friederici et al., 1993). In the final phase of the model, the processes associated with structural integration, reanalysis and repair of previously detected morphosyntactic violation (the P600) take place.

In agreement violation studies, the LAN typically occurs as part of a biphasic ERP response consisting of a LAN followed by a P600 (e.g., Barber & Carreiras, 2005 for Spanish; see Molinaro, et al., 2011, for a review). However, the LAN is less robust than the P600 and less consistently elicited. One of the reasons may be due to morphological differences among the languages under study. For example, while the LAN was found in Spanish (e.g., Barber & Carreiras, 2005), no LAN was reported for agreement violations in Dutch (e.g., Hagoort, 2003; Hagoort, et al., 1993; Popov & Bastiaanse, 2018). Another reason for LAN volatility may be due to methodological issues, such as the choice of the reference electrodes (see Molinaro et al., 2014, for an overview). Tanner (2014) suggests that LAN reflects individual differences in language processing rather than processing morphosyntactic violations. LAN may also reflect syntactic working memory costs (i.e., the maintenance of linguistic information), rather than syntactic integration costs embodied by the P600, as demonstrated by several long-distance dependency processing studies (e.g., Fiebach et al., 2002; Kluender & Kutas, 1993). An investigation of the factors influencing the presence/absence of the LAN in ERP studies is outside the scope of this thesis. However, the volatility of LAN in studies investigating agreement violation processing in typical readers is worth bearing in mind.

1.6.2.1 LAN in Dyslexia Research

To date, only a handful of studies have reported a LAN (Sabisch et al., 2006) or a LAN-like anterior negativity (Cantiani et al., 2015; Rüsseler et al., 2007) in individuals with dyslexia. Sabisch et al. (2006) studied phrase-structure violations in auditory sentence comprehension of passive constructions by German children with and without dyslexia. The sentences in the syntactic violation condition consisted of a noun, an auxiliary, and a preposition. An adjective or a noun is expected to follow a preposition, but instead, a past participle was presented (e.g., *Das Eis wurde im gegessen:* 'The ice cream was in-the eaten'). For children without dyslexia, an early-onset bilaterally-distributed anterior negativity was reported, while children with dyslexia showed no right-sided negativity and a delay in the left-lateralized anterior negativity. This LAN was followed by a P600 for both groups (see Section 1.6.3.1 on the P600 in dyslexia research). Since LAN is thought to be involved in the highly automatic process of phrase structure building, the authors concluded that children with dyslexia exhibit syntactic processing deficiencies. Moreover, the bilaterally-distributed anterior negativity in children without dyslexia was interpreted as these children using right-hemisphere prosodic cues for comprehension, whereas children with dyslexia were argued to demonstrate an impairment in phonological processing indicated by a lack of topographic distribution across the right hemisphere.

A LAN-like anterior negativity was reported for Italian children with dyslexia in response to auditorily presented subject-verb disagreement (Cantiani et al., 2015). In another study, Rüsseler et al. (2007) investigated syntactic processing in adults with dyslexia on a gender judgement task. Participants were required to judge written word pairs, consisting of a noun and an article, which were either matching (e.g., *das– Haus:* 'the$_{\text{N(euter)}}$ – house$_{\text{N}}$') or mismatching with respect to nominal gender (e.g., **das – Chemie:* 'the$_{\text{N}}$ – chemistry$_{\text{F(eminine)}}$'). They found that anterior negativities in response to gender disagreement were delayed and had a longer persistence in adults with dyslexia than adults without dyslexia. In summary, although the LAN is inconsistently reported, the results of all three studies that elicited a LAN(-like) component in individuals with dyslexia interpreted their findings as evidence for a syntactic processing difficulty in dyslexia.

1.6.3 P600

Finally, the P600 – or as it was initially called, syntactic positive shift (SPS) (Hagoort et al., 1993) – is a positive-going waveform that was first reported by Osterhout and Mobley (1992) and Hagoort et al. (1993). It occurs roughly between 500 ms and 900 ms post-stimulus onset, with a posterior-central scalp distribution and a peak at around 600 ms in the centro-parietal region. According to Friederici's (2002) auditory sentence processing model, LAN precedes the P600 as an indication of early, automatic morphosyntactic processing and the P600 follows in a more controlled reanalysis effort. Previous research has interpreted the P600 in both auditory and visual paradigms as reflecting morphosyntactic reanalysis and repair of the syntactic structure that was initially built (see Molinaro et al., 2011, for a review). Furthermore, the P600 has also been associated with difficulties with morphosyntactic integration and increased processing load (e.g., Kaan et al., 2000; Molinaro et al., 2011; Osterhout & Mobley, 1995; Popov & Bastiaanse, 2018). According to Hagoort and Brown (2000), there are two distinct phases of the P600, reflecting different topographies: the early P600 and the late P600. The early P600 typically occurs between 400 ms and 700 ms post-stimulus onset with a broad scalp distribution and is associated with morphosyntactic integration. The late P600 roughly corresponds to the time window between 600 ms and 900 ms after a stimulus and is elicited by reanalysis and repair (e.g., Barber & Carreiras, 2005; Hagoort & Brown, 2000; Kaan & Swaab, 2003; Molinaro et al., 2008; Popov & Bastiaanse, 2018; Popov et al., 2020).

1.6.3.1 P600 in Dyslexia Research

Although the P600 is a fairly robust ERP component that has received ample attention in sentence processing research (see Kutas et al., 2006, for an overview), research on the P600 and morphosyntactic processing in developmental dyslexia is scarce. This is primarily due to morphosyntactic impairments not presenting themselves as a core deficit in dyslexia. Consequently, high-level linguistic processes (e.g., morphosyntax and semantics) have been studied far less than low-level processes (including phonemic and acoustic processing, e.g., with the MMN; Cantiani et al., 2013b). Most studies on the P600 in dyslexia have found a delay in the onset of the P600 (e.g., Cantiani et al., 2013a; Miller-Shaul, 2005; Rispens et al., 2006), a longer latency (Leikin, 2002), as well as a different topographic distribution compared to typical readers (Cantiani et al., 2013a, 2013b; Rispens et al., 2006; but see: Sabisch et al., 2006). The delayed P600 in participants with dyslexia has been interpreted as evidence for a morphosyntactic processing weakness in dyslexia (e.g., Cantiani et al., 2013a). Furthermore, the delay in the onset of the effect in adults with dyslexia for the P600 component (e.g., Rispens et al., 2006) has also been found for other ERP components (e.g., Breznitz & Leikin, 2000; Helenius et al., 1999; Sabisch et al., 2006) and could reflect a generally slower processing of these individuals (e.g., Breznitz & Misra, 2003). For instance, Miller-Shaul (2005) reported a delayed P600 in Hebrew-speaking adults with dyslexia compared to typical readers on various visually presented lexical decision tasks. These adults with dyslexia showed longer lexical decision times for both words and non-words, which was interpreted as indicating that adults with dyslexia needed additional time to retrieve the meaning of a word from long-term memory.

Some studies (e.g., Cantiani et al., 2013a, 2013b) have reported qualitative differences in the ERP pattern between the groups. More specifically, they found an additional ERP component only for adults with dyslexia (an additional 'N400-like' component: Cantiani et al., 2013a; an additional P600-like Positivity: Cantiani et al., 2013b). This was interpreted as reflecting a compensatory mechanism that adults with dyslexia used in constructing implicit grammatical rules. The authors (Cantiani et al., 2013a, 2013b) conclude that their results indicated a different processing mechanism in adults with dyslexia than those without dyslexia, as well as a morphosyntactic weakness in individuals with dyslexia, which was not visible on standard dyslexia diagnostic tests. Additionally, Cantiani et al. (2013b) could not directly and reliably link the observed morphosyntactic processing weakness to an underlying phonological deficit and concluded that the impairment in morphosyntactic processing in dyslexia is not dependent on low-level phonological processing.

1.6.4 Advantages and Limitations of Using ERPs

ERP experiments are non-invasive, relatively inexpensive and offer very precise temporal resolution, even in the absence of an overt behavioral response (e.g., pressing a button). Thus, they are a particularly appropriate tool for studying language processing in a wide range of populations, including children, individuals with language or speech impairments and clinical populations. Furthermore, ERPs enable us to observe and measure millisecond-by-millisecond (or even more fine-grained) differences in language processing. This excellent temporal resolution is unmatched, even by methods such as fMRI (Functional Magnetic Resonance Imaging) or PET (Positron Emission Tomography).

Another advantage of ERPs is that the ERP components, paradigms and tasks are well established in language research (Woodman, 2010). This enables us to utilize a large body of literature exploring these components in different tasks and languages. With the use of ERPs, we can observe an entire cognitive process as it unfolds, as compared to only seeing its end, as is the case in behavioral research (Bentin, 1989). This is especially important for reading and listening, since they consist of complex cognitive, sensory and motor processes (Bentin, 1989). Finally, for research on dyslexia, ERPs seem to offer a more sensitive measure of language processing than behavioral studies. This is especially true for morphosyntactic processing differences between adults with and without dyslexia. These differences are more subtle than for phonological processing and are thus frequently only visible through the use of ERPs rather than on a behavioral grammaticality judgement task (e.g., Rispens, et al., 2006).

However, one must also keep in mind the major drawbacks of this technique. A limitation of ERPs lies in difficulties with the interpretation of waveforms, as well as the inevitable artefacts that arise through movement (including speaking). The artefacts render the use of ERPs challenging for production studies, since the ERP effects can be masked by potential movement (Luck, 2005). Finally, there is the inverse problem, which refers to the difficulty in localizing the actual source of electrical activity in the brain, since ERPs are measured on the scalp. In theory, an infinite number of possible sources is possible for a single electrical signal, which is why we cannot accurately localize the source of neural activity solely from the surface of the scalp (Luck, 2005). As a result, ERPs have poor spatial resolution, which is not the case with neuroimaging techniques (e.g., the fMRI) (Luck, 2005).

1.7 Advantages and Limitations of Using Self-Paced Reading

Our original plan to use ERPs to investigate agreement violation processing in adults with dyslexia could not be achieved due to the COVID-19 pandemic. Therefore, for the final study in this thesis, we used self-paced reading (SPR) to investigate subject-verb disagreement processing in adults with dyslexia. SPR is a computerized method for measuring reading times of a segment (i.e., a word or a phrase) in a sentence and participants' responses to experimental stimuli (e.g., grammaticality judgements). This method was developed by psycholinguists in the 1970s (Aaronson & Scarborough, 1976; Mitchell & Green, 1978). Nowadays, SPR is used frequently in second language research in order to measure both linguistic performance (i.e., reading times) and linguistic competence (i.e., grammaticality judgements) (Jegerski, 2014).

In an SPR experiment, participants are required to read word-by-word, as words are displayed on the computer screen and each new word appears with the press of a button. Thus, participants determine their own reading speed. Words in an SPR experiment can be presented in a cumulative (the words that are presented stay on the screen and the entire sentence is displayed once the participant reaches the sentence ending) or non-cumulative manner (only one word at a time is displayed on the screen). Additionally, words can be in the center of the screen (where each new word or phrase replaces the previous one in the center of the screen) or linear (presented from left to right with no overlap, just like in normal reading). However, the cumulative presentation is rarely used, since most participants then develop a strategy by revealing several words or segments at a time and only then reading them, which defeats the purpose of a reading time-experiment (e.g., Ferreira & Henderson, 1990; Jegerski, 2014; Just et al., 1982). In a non-cumulative word-by-word presentation, participants are not able to re-read words (unlike in eye tracking), which prevents the above-mentioned strategies by participants and enables more precise time-locking to a word or phrase. A word-by-word SPR presentation also enables the experimenter to conduct certain experimental manipulations (e.g., tax the participants' working memory, since participants need to store the entire sentence in memory), but this can also be a disadvantage of this type of presentation. Linear sentence presentation is predominantly used, since it resembles real-life reading more than center presentation (which is preferred for methods such as ERPs). Therefore, almost all SPR studies now use a non-cumulative linear presentation, which is also known as the *moving window(s)* technique, since button presses reveal the unmasked words in a manner that resembles a moving window on the computer screen (Jegerski, 2014).

The advantage of this SPR technique is that it offers detailed information on participants' reading times, and response times and accuracy, since it requires the reader to consider each word in a sentence. SPR experiments are also inexpensive and efficient. In other words, they do not require expensive equipment that needs to be adjusted during the experiment, and can be conducted remotely, so that participants are not required to be present in the lab in order to take part in an experiment. It is also possible to combine SPR with other methods – for instance, into a concurrent SPR and ERP experimental design. Another advantage of SPR is that it does not only detect processing effects – increased reading times, which are associated with increased processing difficulty – on the target word(s), but also delayed or persistent effects in the *spill-over* (i.e., regions(s) immediately following the target word) and *wrap-up* regions (i.e., region at the end of a sentence). One of the major disadvantages of SPR is that sentences need to be highly segmented into word-by-word or phrase-by-phrase presentation in order to obtain detailed reading-time data, which is not an entirely natural mode of reading. Although participants nowadays are more accustomed to digital reading at their own pace (e.g., text messages, browsing the internet with a smart phone, etc.), they still need to press a button in order to view the next segment in a SPR experiment, which could present a somewhat unnatural distraction in SPR research (Jegerski, 2014).

1.8 Reading as the Modality of Presentation in Online Studies on Dyslexia

Regardless of the exact definition used, the core of the deficit in dyslexia is inaccurate or disfluent reading at the word level. So far, there has been no research with individuals with dyslexia on either ERP agreement violation processing in reading, or SPR. As two studies in this thesis (Chapters 3 and 4) use reading as the modality of presentation, this section provides support for using written stimuli in linguistic studies with individuals with dyslexia with different methods. In particular, previous studies used written stimuli with eye tracking, event-related potentials (ERPs – in particular on the N400 ERP component), functional magnetic resonance imaging (fMRI), and magnetoencephalography (MEG).

Eye tracking is an example of an online processing method that relies on the visual mode of presentation and a number of studies have used it in dyslexia to investigate processing of visually presented words and non-words (e.g., De Luca et al., 2002; Hutzler et al., 2006), sentences (e.g., Horowitz-Kraus & Breznitz, 2011; Hutzler & Wimmer, 2004) and text (e.g., Hyönä & Olson, 1995; Prado et al., 2007). The majority of eye-tracking studies report that, compared to typical readers, individuals with dyslexia exhibit longer fixations (i.e., times during which the eye stays still), shorter saccades (i.e., eye movements from point to point, between fixations), and a larger number of regressions (i.e., short backwards eye movements to previously presented material) (e.g., De Luca et al., 2002; Hawelka et al., 2010; Hutzler & Wimmer, 2004; Hutzler et al., 2006; Olson et al., 1983; see Bilbao & Piñero, 2020, for a review). However, the general consensus in current eye-tracking literature on dyslexia is that the atypical eye movements of individuals with dyslexia are a secondary consequence of dyslexia, rather than the cause of the reading impairment (e.g., Nilsson Benfatto et al., 2016; Olson et al., 1983).

Other studies have used written presentation combined with methods with higher temporal or spatial resolution (e.g., fMRI: Schultz et al., 2008; MEG: Helenius et al., 1999; EEG: Rüsseler et al., 2007). Of particular relevance to this thesis is the fact that a large number of studies on lexical-semantic processing and the N400 in children and adults with dyslexia have used written stimuli (e.g., Ackermann et al., 1994; Hasko et al., 2013; McPherson et al., 1998; Meng et al., 2007; Neville et al., 1993; Robichon et al., 2002). Most studies using the written modality report a delayed and attenuated N400 in individuals with dyslexia (e.g., Jednorog et al., 2010; Rüsseler et al., 2007). These results are comparable to those that used auditory presentation that also typically report anomalies in the N400 in individuals with dyslexia (e.g., Brandeis et al., 1994; but see: Bonte & Blomert, 2004; Sabisch et al., 2006).

In summary, previous research investigated linguistic processing in individuals with dyslexia with written stimuli, which supports the use of the visual mode of presentation in our studies on adults with dyslexia.

1.9 Linguistic Background

Agreement is a syntactic process for establishing a relationship between elements in a sentence (e.g., a noun and a verb) at the level of syntax. Before an agreement relationship occurs, the morphological features of a noun (e.g., gender, number, or person) need to be retrieved and checked (e.g., Carnie, 2011; Kerstens, 1993; Pesetsky & Torrego, 2007). In the section that follows, we will provide a brief overview of the two types of agreement used in this thesis for Dutch, the language of investigation: gender and number agreement, on the one hand, and subject-verb agreement, on the other.

1.9.1 Gender in Dutch

Dutch exhibits a two-way system of nominal gender marking: neuter gender and common gender (Van Berkum, 1996). Historically, common gender nouns used to be separated into masculine and feminine but are now collapsed into one category: common gender. Common and neuter nouns display a frequency asymmetry, with common nouns comprising approximately 75% of all Dutch nouns (Van Berkum, 1996). Gender in Dutch is largely arbitrarily assigned (Deutsch & Wijnen, 1985), so that it cannot be predicted from the word form itself.

In Experiments 1 and 2, the focus was on the processing of nominal gender agreement (more specifically: article-noun and adjective-noun agreement) and, therefore, only the details of these two types of agreement paradigms will be outlined here. Unlike morphologically rich languages such as Spanish, in which gender is overtly marked on the noun (e.g., masculine: *libr-**o**,* 'book'; feminine: *literatur-**a*** 'literature'), Dutch exhibits no such overt gender marking on the noun. In other words, with the exception of diminutives, Dutch nouns do not have a morphological suffix for gender. In general, gender marking of a noun is only visible on the elements that enter into an agreement relationship with the noun, such as articles (e.g., definite articles: *de* with common nouns, or, *het* with neuter nouns), adjectives (e.g., the inflectional ending -*e* is not used on adjectives after an indefinite article when the noun is neuter; see Table 1.1) and relative pronouns (e.g., *het boek dat …*: 'the book that …'; *de tafel die …*: 'the table that…'; Van Berkum, 1996).

All Dutch count nouns require an article: neuter nouns in Dutch take the definite article *het* and common nouns take the article *de.* For indefinite articles, both neuter and common nouns take *een,* with no gender distinction. Finally, for plural, Dutch nouns exhibit a different type of syncretism, with all nouns taking the plural article *de.* Table 1. below provides an overview of the Dutch article system.

Table 1.1 Overview of the Dutch article system.

	Singular		Plural	
	Common	Neuter	Common	Neuter
Definite	*de*	*het*	*de*	*de*
Indefinite	*een*	*een*	-	-

The Dutch adjectival inflection system consists of only two forms: the more common –*e* ending and the bare (ø) form, which is associated with singular indefinite neuter nouns. In all other contexts, the adjective is inflected similarly for all nouns (-*e*). Table 1.2 provides an overview of the Dutch adjectival inflectional paradigm, and some examples of paradigms with definite or indefinite singular nouns are provided in examples 1-4:

Table 1.2 Overview of the Dutch adjectival inflection system.

	Singular		Plural	
	Common	Neuter	Common	Neuter
Definite	-*e*	-*e*	-*e*	-*e*
Indefinite	-*e*	-*ø*	-*e*	-*e*

(1) De mooie fiets
The beautiful bicycle$_{C(ommon)}$
'The beautiful bicycle'

(2) Het mooi**e** boek
The beautiful book$_{N(euter)}$
'The beautiful book'

(3) Een mooie fiets
A beautiful bicycle$_{C}$
'A beautiful bicycle'

(4) Een mooi boek
A beautiful book$_{N}$
'A beautiful book'

Dutch nouns are marked for number in singular or plural. Plural nouns are always operationalized by means of a plural suffix: either the suffix -*s* (e.g., *vogel* 'bird' – *vogels* 'birds') or the suffix -*en* (e.g., *dorp* 'village' – *dorpen* 'villages').

1.9.2 Subject-Verb Agreement

In subject-verb agreement in Dutch, the verb must agree with the subject of the sentence. In other words, the features of the verb only need to agree with the features of the subject in person (first, second or third) and number (singular or plural). This is in contrast to other languages where the verb may also agree with the subject in gender (feminine, masculine, neuter), case, and/or animacy, among other features (Corbett, 2006). In Dutch present tense, the bare verb stem is used for first person singular, stem *-t* is used for second and third person singular, while stem *-en* is used for all plural verbs. Examples are provided in 5-7 below:

(5)	Ik	speel		
	'I	play'		
(6)	Jij	/hij	/zij[1]	spelt
	'You SG	/he	/she	play(s)
(7)	Wij	/jullie	/ze	spelen
	'We	/you PL	/they	play

Dutch is typically assumed to be a subject-object-verb (SOV) language, since this is the word order that appears in embedded clauses (Koster, 1975; but see: Zwart, 1993, for a view of Dutch as an SVO language). However, in main clauses, the subject is followed by the finite verb, which is marked for tense and agreement. This is known as the verb-second rule (Koster, 1975). See the following example:

(8)	Sophie	leest	een	boek
	Sophie	reads	a	book
	'Sophie is reading a book.'			

In embedded clauses, such as the ones used in Experiment 3, the basic word order is SVO, since the verb occupies the final position in the sentence:

(9)	... omdat	Sophie	een	boek	leest.
	... because	Sophie	a	book	reads
	'... because Sophie is reading a book.'				

1.10 Main Research Questions

In this section, we outline the main research questions of this thesis. The thesis aims to contribute to the knowledge on the morphosyntactic processing in Dutch

1 In Dutch, *zij* and *ze* are used interchangeably. Both *zij* and ze refer to the third person singular feminine form and the third person plural form.

adults with dyslexia by examining their sensitivity to the auditory and visual processing of agreement violations. In addition to studying both the spoken and the written modality, we investigate the contribution of linear distance (i.e., the distance between the elements in an agreement relationship) as a means of manipulating the WM load and evaluating its effect on morphosyntactic processing in dyslexia. We used both ERPs and SPR techniques.

The main research questions of this thesis are as follows:

Research Question 1: Is there a difference in the performance of adults with and without dyslexia on a behavioral grammaticality judgement task?

Research Question 2: Does the neurophysiological pattern (as measured with ERPs) during processing of morphosyntactic information differ between adults with and without dyslexia?

Research Question 3: Is there a difference between written and auditory processing of the same stimuli for adults with dyslexia?

Research Question 4: Is there a difference between the processing of within-phrase and across-phrase disagreement for adults with dyslexia?

To answer these research questions, three experiments have been developed.

Experiments 1 and 2 used the same stimuli and focused on within noun-phrase gender and number agreement (article-noun and adjective-noun agreement). Experiment 1 explores gender and number disagreement in listening, and Experiment 2 in reading for adults with dyslexia. In these experiments, we used ERPs with a behavioral grammaticality judgement task. We chose to use ERPs, since agreement processing differences between adults with and without dyslexia are subtle and they might only be visible using sensitive measures, such as ERPs, rather than a behavioral task (Cantiani et al., 2013a; Rispens et al., 2006).

Only a handful of studies investigated the processing of gender and number disagreement behaviorally and using ERPs. Jiménez et al. (2004) examined written gender and number agreement judgements in Spanish children with and without dyslexia, but did not distinguish between the two types of agreement. The authors found that children with dyslexia performed worse than their peers without dyslexia on the gender and number agreement sentence completion task than on the other morphosyntactic tasks. A single ERP study on gender (dis)agreement processing in written word pairs in German adults with dyslexia was conducted by Rüsseler et al. (2007). They found delayed anterior negativities for adults with dyslexia that persisted longer than in adults without dyslexia, which was interpreted as a syntactic processing difficulty. Taken together, the results of these two studies point to a difficulty with gender and number agreement processing in individuals with dyslexia.

To date, there have been no agreement violation processing studies in the visual modality using ERPs with adults with dyslexia. Thus, it is not known how reading as the presentation modality influences agreement processing in adults with dyslexia. Therefore, we compared the two modes of presentation by using the same stimuli in both experiments in order to disentangle modality-specific mechanisms underlying the corresponding ERP effects.

The final experiment in this thesis, **Experiment 3**, focused on across-phrase subject-verb agreement in SPR. In Experiment 3, we were primarily interested in the processing of linear distance between the subject and the verb, which was measured with reading times for the critical regions (the verb, the spillover – region following the verb, and the final word) and a grammaticality judgement task at the end of a sentence. Although SPR is a frequently used method in psycholinguistics (Jegerski, 2014), no previous studies (on agreement processing or otherwise) in dyslexia have been conducted with the use of SPR.

Both behavioral and ERP studies across different languages have investigated the processing of subject-verb disagreement in children and adults with dyslexia (behavioral: Rispens & Been, 2007; Rispens et al., 2004, in Dutch; ERPs: Cantiani et al., 2013a, 2013b, 2015, in Italian and German; Rispens et al., 2006, in Dutch). In general, these studies have reported a lack of sensitivity to subject-verb disagreement in individuals with dyslexia compared to individuals without dyslexia, as indicated by a poorer performance on a grammaticality judgement task (Rispens et al., 2004; Rispens & Been, 2007) or a delayed and/or reduced amplitude of the P600 in response to subject-verb disagreement (e.g., Rispens et al., 2006). Furthermore, Cantiani and colleagues reported an additional (Cantiani et al., 2013a, 2013b) or qualitatively different ERP component (Cantiani et al., 2015) in response to subject-verb disagreement in individuals with dyslexia compared to their peers without dyslexia. Taken together, these studies suggest that individuals with dyslexia display difficulty with processing adjacent (i.e., within-phrase) subject-verb agreement, both behaviorally and in ERPs. In Experiment 3, we investigate both within phrase (i.e., short-distance dependency) and across-phrase (i.e., long-distance dependency) subject-verb disagreement processing. Finally, we compare the results for the two types of agreement (within-phrase: Experiments 1 and 2 vs. across-phrase: Experiment 3) and the two types of dependencies in terms of linear distance (i.e., intervening words between the elements in an agreement relationship, e.g., subject and verb).

1.11 Outline

The following two chapters, Chapter 2 and Chapter 3, introduce a gender and number disagreement study with Dutch adults with dyslexia in listening and reading with ERPs, respectively. The last experimental chapter, Chapter 4, examines the influence of linear distance in subject-verb disagreement processing on a self-paced reading task. The final Chapter 5 presents a general discussion of all the previous experimental chapters in relation to the main research questions.

CHAPTER 2

Event-Related Potential (ERP) Responses to Gender and Number Disagreement in Adults with Dyslexia in Listening

2.1 Introduction

Developmental dyslexia (henceforth: "dyslexia") is a specific learning difficulty that manifests itself as an impairment in the acquisition of fluent reading. It is characterized by difficulties in word recognition (low accuracy and/or speed), as well as by poor decoding and/or poor spelling and writing skills (e.g., American Psychiatric Association, 2013; Lyon et al., 2003). Dyslexia is by far the most common learning difficulty (e.g., Lyon, 1995) with a neurobiological origin (e.g., Lyon et al., 2003) and persists well into adulthood (e.g., Shaywitz et al., 1999). This "unexpected difficulty in reading" (Shaywitz, 1998, p. 307) is not influenced by intelligence, education, motivation, or chronological age (e.g., American Psychiatric Association, 1994; Shaywitz, 1998).

The theory on the cause of dyslexia that has gained the most support is the *phonological deficit theory*, which links the underlying impairment in dyslexia to problems with perceiving, storing and retrieving speech sounds as phonological units of information (e.g., Snowling, 1995, 2000). However, specific problems with linguistic skills other than phonology, including (morpho)syntax, have also been reported in children and adults with dyslexia. Various behavioral studies have identified difficulties in both auditory comprehension and oral production of morphology and syntax. These include lack of sensitivity to inflectional morphology (production: Altmann et al., 2008; Joanisse et al., 2000; Robertson et al., 2013; comprehension: Casalis et al., 2013; Rispens et al., 2004), and problems with the comprehension of complex syntactic structures, including relative clauses, passives, and clauses demonstrating syntactic binding principles (e.g., Bar-Shalom et al., 1993; Casalis et al., 2013; Leikin & Assayag-Bouskila, 2004; Mann et al., 1984; Robertson & Gallant, 2019; Robertson & Joanisse, 2010; Shankweiler & Crain, 1986; Stein et al., 1984; Stella & Engelhardt, 2019; Waltzman & Cairns, 2000; Wiseheart et al., 2009). Nonetheless, most studies in the field of dyslexia have focused on phonological skills, whereas much less is known about morphosyntactic processing, especially in adults with dyslexia. The present study aims to bridge this gap by focusing on morphosyntactic processing of sentences containing nominal gender and number disagreement in young Dutch adults with dyslexia. It uses a listening task with grammaticality judgements and the measurement of event-related potentials (ERPs).

2.1.1 Linguistic Background

Agreement is a syntactic operation that typically includes the retrieval and checking of morphological features (e.g., gender, number, or person) in order to establish a syntactic relationship between different sentential elements (e.g., Carnie, 2011; Kerstens, 1993; Pesetsky & Torrego, 2007). In terms of gender, Dutch is language that exhibits a two-way system of nominal gender marking:

neuter gender and common gender (e.g., Van Berkum, 1996). Furthermore, Dutch possesses a non-transparent system of gender marking: nouns are predominantly morphologically opaque and not overtly morphosyntactically marked for gender.[2] As a consequence, gender in Dutch is known to cause difficulties for both typical and atypical populations (e.g., Bastiaanse et al., 2003; Blom et al., 2008; Orgassa, 2009). In general, gender marking of a noun is only visible on the elements that enter into an agreement relationship with the noun, such as, for example, articles (e.g., definite articles: *de* with common nouns, or, *het* with neuter nouns in singular), and adjectives (e.g., the inflectional ending -*e* is not used on adjectives after an indefinite article when the noun is neuter: *het mooi-**e** dorp*$_{N(euter)}$: 'the beautiful village'; *een mooi-ø dorp*$_{N}$: 'a beautiful village'). While gender is a lexical feature of the noun and part of a word's lemma (e.g., Levelt et al., 1999; Van Berkum, 1996), number in Dutch is overtly morphologically marked via a suffix on the noun (plural nouns: plural suffix *-en* or *-s*; singular nouns are not overtly morphologically marked).

In this study, we used the same stimuli with gender and number disagreement as Popov (2017), so we will explore his experimental paradigm further. In these stimuli, gender disagreement was created by a mismatch between an indefinite article (*een*), an adjective with a gender suffix *-e* and the target noun, which is morphologically opaque with respect to gender (e.g., grammatical: *een mooi dorp*$_{N}$; ungrammatical: **een mooie dorp*$_{N}$: 'a beautiful village'). The parser only detects the violation once it reaches the target noun, since the inflectional adjectival suffix *-e* is the only cue to differentiate between grammatical and ungrammatical sentences in this condition. For number disagreement, the mismatch comprises of a singular/neuter article (*het*), the adjectival suffix *-e* and the target noun, which is marked with a plural suffix *-en* (e.g., **het mooie dorpen*: 'the beautiful villages'). Thus, sentences with a noun phrase (NP) that is ungrammatical in relation to number contain the *het*-article, while sentences with NPs that are grammatical contain the plural/common gender (*de*; e.g., *de mooie dorpen*). Thus, the perceptual salience of the violation in the number condition is higher than the salience of the violation in the gender condition, since the latter is marked with both lexical (*het*) and double inflectional (*mooi-e dorp-en*) cues.

In contrast to the overt plural suffix in Dutch number (e.g., *-en* or *-s*), Dutch nouns are morphologically opaque for gender and thus gender is less perceptually salient than number. With regards to the structural repair options in Popov's (2017) stimuli, gender condition only had one repair option (i.e., **een mooie*$_{C(common)}$ *dorp*$_{N}$ > *een mooi*$_{N}$ *dorp*$_{N}$), while the number condition contains two potential repair

2 However, diminutive nouns are an exception, as they are marked with a *–je* suffix (e.g., *muisje* 'little mouse') and are always neuter.

options, rendering it more complex to repair (i.e., **het*$_{SG}$ *mooie*$_{SG/PL}$ *dorpen*$_{PL}$ > *het*$_{SG}$ *mooie*$_{SG}$ *dorp*$_{SG}$; **het*$_{SG}$ *mooie*$_{SG/PL}$ *dorpen*$_{PL}$ > *de*$_{PL}$ *mooie*$_{PL}$ *dorpen*$_{PL}$*)*. We will come back to the issue of structural repair in gender and number disagreement later in the Discussion.

2.1.2 Gender and Number Disagreement Processing and ERPs

Research on agreement processing has identified three main ERP components relevant for agreement computation: the left anterior negativity (LAN), the N400, and the P600. These ERPs are typically elicited using a violation paradigm, like that described in the previous section, in which grammatical (baseline) sentences are compared to corresponding ungrammatical sentences, differing only in the target word. Recently, it has been demonstrated that one-to-one mapping between ERP components and a single linguistic level (e.g., the N400 – semantics, the P600 – morphosyntax) is an oversimplification (e.g., see Kim & Osterhout, 2005, on the semantic P600). Furthermore, multiple instantiations of these components have been identified and their function(s) debated (see, e.g., Brouwer et al., 2012; Sassenhagen et al., 2014). However, since the functional classification of ERP components is outside the scope of the current study, we will only focus on agreement processing, in which the most prevalent ideas are still broadly based on the auditory sentence processing model (Friederici, 2002), and are nicely summarized in the review by Molinaro et al. (2011).

The LAN is a left-lateralized negative-going deflection with an anterior distribution and a peak between 300 and 500 ms. According to Friederici's (2002) model of auditory sentence processing, the LAN is an indication of an early and automatic violation detection during morphosyntactic processing (see also Molinaro et al., 2014). The LAN precedes the P600, a positive-going deflection with a peak at around 600 ms, and is associated with morphosyntactic repair and reanalysis, as well as difficulties with morphosyntactic integration (e.g., Kaan, 2000; Molinaro et al., 2011; Osterhout & Mobley, 1995). According to Hagoort and Brown (2000), there are two distinct phases of the P600 (early and late), reflecting different topographies and elicited by different stimuli. The early P600 typically occurs between 500 ms and 700 ms post-stimulus onset with a broad scalp distribution and represents morphosyntactic integration difficulty. The late P600 roughly corresponds to the time window between 700 ms and 1000 ms post-stimulus onset and is associated with reanalysis and repair (e.g., Barber & Carreiras, 2005; Hagoort & Brown, 2000; Kaan & Swaab, 2003; Molinaro et al., 2008; Popov & Bastiaanse, 2018; Popov et al., 2020).

Most ERP studies examining gender and/or number disagreement processing have reported a P600 in response to morphosyntactic violations. While some studies have reported a monophasic P600 following agreement violations (e.g., Hagoort & Brown, 1999, 2000; Kaan & Swaab, 2003; Wicha et al., 2004), others have found a biphasic LAN-P600 response (e.g., Barber & Carreiras, 2005; Caffarra et al., 2019; Molinaro et al., 2008; Roehm et al., 2005). LAN is inconsistently reported in agreement studies and the volatility of LAN as a marker of automatic morphosyntactic processing has been well-documented (e.g., Molinaro et al., 2011, 2014; Steinhauer & Drury, 2012; Tanner, 2015). Notably, studies on gender and/or number disagreement in Dutch have reported only a P600 and no LAN (e.g., Hagoort, 2003; Hagoort & Brown, 2000; Loerts et al., 2013; Meulman et al., 2014; Popov & Bastiaanse, 2018; but see: Popov, 2017).

Moreover, studies on the individual processing of gender (e.g., Molinaro, et al., 2008; Wicha et al., 2004) or number (e.g., Hagoort et al., 1993; Kaan & Swaab, 2003), as well as most studies that have investigated gender and number disagreement combined (e.g., Alemán Bañón et al., 2012; Barber & Carreiras, 2005; Nevins et al., 2007; Popov & Bastiaanse, 2018) have consistently elicited the same effect: a P600, which is occasionally preceded by a LAN. Since both gender and number violations generate similar ERP effects, this has led researchers to posit that these types of agreement rely on an identical processing mechanism (e.g., Barber & Carreiras, 2005). However, the complexity of structural repair processes might be different, as reflected in a processing discrepancy between these two types of stimuli in the late stage of the P600 (e.g., Barber & Carreiras, 2005; Popov & Bastiaanse, 2018). Nevertheless, in their study on auditorily presented gender and number disagreement processing in Dutch, Popov (2017) reported a somewhat puzzling result of a biphasic LAN-P600 effect for gender disagreement and a P600 effect for number disagreement. The author attributed the presence of LAN in the gender condition to the auditory modality of presentation and the nature of the stimuli (i.e., the violation in the gender condition was a lexical violation that preceded the end of the word, compared to the word-final violation in the number condition).

2.1.3 Morphosyntactic Processing in Dyslexia with ERPs

Only a handful of studies have investigated morphosyntactic processing in dyslexia using ERPs. A P600 was almost unanimously reported in response to auditorily presented morphosyntactic violations in participants with and without dyslexia (e.g., Rispens et al., 2006; but see: Miller-Shaul, 2005), and some authors report a biphasic ERP response for both groups (e.g., LAN-P600: Sabisch et al., 2006). However, there were temporal differences in the characteristics of the elicited components between individuals with and without dyslexia. For instance, Rüsseler et al. (2007) examined the processing of gender agreement violations in reading in German adults with dyslexia using written word pairs consisting of a definite article and a noun, which (dis)agreed in gender. Their results yielded a LAN-like frontal negativity for gender disagreement for both groups, but adults with dyslexia showed a delay in the onset and a prolonged duration of the elicited negativity, which was interpreted as a difficulty in syntactic integration (Rüsseler et al., 2007). While Sabisch et al. (2006) report a comparable P600 effect in both children with and without dyslexia in response to passive sentences with phrase-structure violations, they also found qualitative differences and a delay in the onset of the LAN-like component preceding the P600 in children with dyslexia. The authors interpret these results as a delay in the early and highly automatic processes of phrase structure building (the LAN) in children with dyslexia, as opposed to their unimpaired controlled mechanism of syntactic reanalysis (the P600). However, several other authors have found a delay in the onset and peak of the P600 in the group with dyslexia (e.g., Cantiani et al., 2013a; Miller-Shaul, 2005; Rispens et al., 2006). This difference in the P600 latency between individuals with and without dyslexia is typically interpreted as either a morphosyntactic weakness in adults with dyslexia, or a lack of sensitivity to inflectional morphology (e.g., Cantiani et al., 2013a; Rispens et al., 2006).

Cantiani and colleagues have reported the presence of an additional ERP component in two auditorily presented studies in response to agreement violations only in the group with dyslexia (Cantiani, et al., 2013a, 2013b). For instance, Cantiani et al. (2013b) reported an Early (Syntactic) Negativity for both adults with and without dyslexia in response to spoken subject-verb agreement violations in German, while the group of adults with dyslexia showed an additional Positivity (interpreted as a P600). In the study on Italian adults with dyslexia (Cantiani et al., 2013a), the authors reported a P600 for typical readers in response to subject-verb disagreement in Italian, but adults with dyslexia showed a biphasic ERP pattern consisting of an ‘N400-like’ component and the P600. The presence of an additional component only in adults with dyslexia was interpreted as a compensatory mechanism that adults with dyslexia use in constructing implicit morphosyntactic rules. This finding is similar to Byrne’s (1981) behavioral results for children with dyslexia, which suggested that children with dyslexia have a general syntactic weakness, which causes them to operate at a developmentally lower level of linguistic processing. The ERP findings by Cantiani et al. (2013a) could also be interpreted as in example of *good-enough parsing* in dyslexia (Ferreira et al., 2002; see Ferreira & Patson, 2007, for a review). According to this theory, the parser, albeit in typical readers, will often accept an incomplete or incorrect (i.e., ‘good-enough’) sentence representation during sentence processing, rather than build a complete, accurate and detailed sentence representation. Moreover, Cantiani et al. (2013a) explained the presence of the additional N400-like component in adults with dyslexia by relating it to the ERP components found in second/foreign language acquisition (L2) literature. In general, the progression between the stages of L2 proficiency from low to high (near-native) is accompanied by both qualitative and temporal changes in ERPs (Steinhauer, 2009, 2014).

Finally, most ERP studies on dyslexia have reported a different topographic distribution of the elicited ERP components between individuals with and without dyslexia (e.g., Cantiani et al., 2013a, 2013b; Miller-Shaul, 2005; Rispens et al., 2006; Rüsseler et al., 2007; Sabisch et al., 2006). Regardless of the heterogeneity of these ERP results, it can be inferred that ERPs present a sensitive measure of subtle morphosyntactic processing differences between individuals with and without dyslexia. Furthermore, the results of these ERP studies on dyslexia are similar to the results obtained with different methods, such as eye tracking (e.g., a delay in the comprehension of spoken sentences; Huettig & Brouwer, 2015, for Dutch adults with dyslexia). Altogether, both the ERP and eye-tracking results point to a delay in the speed of auditory processing in dyslexia (e.g., Breznitz & Leikin, 2000; Breznitz & Misra, 2003) and indicate that problems with spoken language processing in dyslexia are present in adulthood.

2.1.4 Current Study

The current study examined the auditory processing of gender and number disagreement in Dutch adults with dyslexia with the use of ERPs. Behavioral and ERP results for adults without dyslexia were collected and reported by Popov (2017) using the same paradigm and materials. We will be comparing our results qualitatively against theirs in a visual descriptive comparison, which will look into the difference in the latency and the distribution of the ERP effects in the two groups.[3] If a P600 is elicited in the current study, as predicted, we will further explore its interpretation in light of structural repair processes, akin to Popov (2017) and Popov and Bastiaanse (2018). We chose to investigate morphosyntactic processing in adults with dyslexia using ERPs as a non-invasive technique that provides insight into language processing as it happens in real-time, since previous studies indicate that morphosyntactic differences between individuals with and without dyslexia are subtle and often only visible through ERPs (e.g., Rispens et al., 2006; Rüsseler et al., 2007; but see: Cantiani et al.,

[3] We will not compare the effects in the two groups directly, because we are interested in the difference in the onset and distribution of the effect (i.e., the P600), rather than the difference in effect size. One of the major reasons that we are not interested in the P600 effect size is that we expect the components to have a different onset in the two groups, which renders comparison of the effect sizes uninterpretable.

2013a, 2013b; Sabisch et al., 2006). The present study is the first to investigate ERP responses to gender and number disagreement in individuals with dyslexia, with previous ERP research on dyslexia predominantly focusing on subject-verb disagreement (e.g., Cantiani et al., 2013a, 2013b, 2015; Rispens et al., 2006).

2.1.4.1 Research Questions and Predictions

In order to investigate the processing of gender and number disagreement in adults with dyslexia in listening using ERPs, we formulated the following research questions:

> **Research Question 1:** Is there a difference in the processing of agreement violations in auditorily presented stimuli between adults with and without dyslexia, as reflected in their ERP responses to gender disagreement and number disagreement when qualitatively comparing the latency and the distribution of those ERP effects?

Prediction 1: We predict that there will be a difference in processing agreement violations between adults with and without dyslexia, which will be reflected in qualitative and/or topographic differences in ERP responses between the groups, based on previous literature (e.g., Cantiani et al., 2013a, 2013b; Rispens et al., 2006). More specifically, since Popov (2017) elicited a biphasic LAN-P600 pattern in response to gender disagreement for the same stimuli as we are using in adults without dyslexia, we might also elicit a delayed LAN-P600 effect.

> **Research Question 2:** In the group of adults with dyslexia, is there a difference in the ERP responses between the two conditions (i.e., number and gender disagreement)?

Prediction 2: We expect gender disagreement to pose more processing difficulties than number disagreement due to the nature of the violations and the difference in perceptual salience of the two conditions. If so, then this processing difficulty should be reflected in a smaller amplitude, delayed or absent ERP effect in the gender than in the number condition, which would then indicate the difficulty of detecting the violation in the gender condition.

2.2 Method

2.2.1 Participants

We recruited 16 participants with dyslexia (5 male; mean age 23.4; age range 18-27 years). Data from 3 participants were discarded prior to the ERP analysis due to the presence of excessive artifacts, leaving a total of 13 participants.

All participants were diagnosed as having clinical dyslexia prior to the experiment and had a valid statement of their dyslexia diagnosis. Participants also reported no other linguistic impairment (e.g., no history of speech therapy) apart from dyslexia, as confirmed by the intake questionnaire. The diagnosis criteria followed in this study were those of the Dutch Dyslexia Foundation (*Stichting Dyslexie Nederland*; SDN et al., 2016). Dyslexia diagnosis was confirmed through a questionnaire and the use of selected behavioral tasks (see below).

In addition, all participants satisfied the following inclusion and exclusion criteria: native speakers of Dutch, right-handed (as assessed by a Dutch adaptation of the Edinburgh Handedness Questionnaire; Oldfield, 1971), no (history of) neurological or psychiatric disorders (e.g., epilepsy, ADHD, or Autism Spectrum Disorders (ASD)), normal or corrected-to-normal vision and no hearing impairments.

All participants received written and verbal information about the study and gave written informed consent before the experiment. Participants received financial compensation of 15 EUR in return for their time. The experiment was approved by the local ethics committee (Research Ethics Committee (CETO), Faculty of Arts, University of Groningen).

2.2.2 Behavioral Measures

At the beginning of the study, a set of short behavioral measures was administered to participants with dyslexia in order to confirm the dyslexia diagnosis, since we could not control how the participants' dyslexia was originally diagnosed. The tests were selected based on the criteria by SDN et al. (2016) and a short protocol for dyslexia assessment (Tops et al., 2012). For diagnosing dyslexia, Tops et al. (2012) found support for the reliability and validity of a select number of tests from a comprehensive assessment battery for dyslexia diagnosis in Dutch (Test voor Gevorderd Lezen en SCHrijven – GL&SCHR, De Pessemier & Andries, 2009). We assessed word reading fluency (One Minute Test, or 'Eén-minuut-test'; Tops et al., 2019), pseudo-word reading fluency (The Klepel, or 'De Klepel'; Van den Bos et al., 1994), and word spelling (spelling subtest of the GL&SCHR) to confirm the dyslexia diagnosis. Additional tests tapping into phonological awareness (Spoonerisms, and Omkeren, or 'Reversals', GL&SCHR), as well as morphology and syntax knowledge (morphology and syntax subtest of the GL&SCHR) were administered. These tests are described in Appendix A.

The scores of participants with dyslexia on the behavioral tests are shown in Table 2.1. Participants with dyslexia displayed either a clinical (< *Pc* 10) or subclinical (< *Pc* 16) score on word reading fluency, pseudo-word reading fluency, and spelling to dictation, thus confirming the dyslexia diagnosis.

Table 2.1 Mean percentile scores of the 13 participants with dyslexia on the behavioral tests compared to normative data.

	M Pc score	*SD*
Dyslexia diagnostic tests		
Word reading fluency	7.3	4.8
Pseudo-word reading fluency	3.6	3.7
Spelling to dictation	6.8	5.4
Other dyslexia tests		
Reversals	14	11.6
Spoonerisms	12	9.3
Morphology & syntax	41.6	17

Note: M Pc = mean percentile score, *SD* = standard deviation.

2.2.3 Materials

The materials used in the experiment are those used by Popov (2017) in his Dutch listening experiment. Full materials can be found in Appendix B. The materials consisted of 160 experimental sentences and 240 fillers. The materials were constructed with the use of 20 unique Dutch nouns, 10 of which were neuter (*het*) nouns and 10 common gender (*de*) nouns. Only *het*-nouns were used as experimental stimuli, whereas *de*-nouns were included as fillers. The nouns used for the experimental sentences were trisyllabic, whereas fillers always contained disyllabic nouns. The nouns were controlled for frequency, so that only high-frequent nouns were selected (CELEX2 lexical database for Dutch; Baayen et al., 1995). The nouns were further controlled for animacy (only inanimate nouns were used), noun-verb homophony (i.e., no nouns were used that could be homophonous to the infinitive form of the verb, e.g., *boek* 'book' > *boeken* 'books$_{\text{Noun}}$'/'to book$_{\text{Verb}}$') and phonological alternations (e.g., irregular plurals, such as *kind* 'child' – *kinderen* 'children', were excluded).

For the experimental items, each noun was used to construct four sentences, with each sentence being used once as grammatical and once as ungrammatical. All stimuli were divided over two lists. Each participant was exposed to only one list. Each target noun appeared twice per list (i.e., four times in total), either in a grammatical or in an ungrammatical sentence. Each list comprised a total of 240 sentences (80 experimental and 160 filler sentences; half grammatical and half ungrammatical). If a grammatical sentence was in List 1, an ungrammatical version of the same sentence was in

List 2. Thus, each participant was exposed to each noun only once, either in a grammatical or in an ungrammatical sentence. Sentences were presented in a pseudo-random order.

The experimental sentences were split into two conditions: gender (40 sentences per list) and number (40 sentences per list). The agreement mismatch in the gender condition was created by a gender mismatch between the adjective and the noun, which created a violation that the parser could recognize only at the end of the target noun (see example 1). In the number condition, the agreement mismatch was created by a number mismatch between the article and the noun and the violation itself could only be recognized once the parser reached the target noun (e.g., example 2).

(1)	Dat	was	een	mooi	compliment	over	haar	werk.
	that	was	a	beautiful$_{N}$	compliment$_{N}$	on	her	work

‘That was a beautiful compliment for her work.’

Dat	was	een	mooi	*compliment	over	haar	werk.
that	was	a	beautiful$_{C}$	compliment$_{N}$	on	her	work

Sentences in the number condition shared an identical structure (2). The plural article *de* in grammatical sentences and the singular neuter article *het* in ungrammatical sentences was followed by an inflected adjective and the target noun. Just like in the gender condition, the target noun was always followed by a prepositional phrase, an adverbial phrase, or a lexical verb.

(2)	De	onverwachte	complimenten	zijn	vaak	het	leukst.
	the$_{PL}$	unexpected$_{PL}$	compliments$_{PL}$	are	often	the	best

‘The unexpected compliments are often the best.’

Het	onverwachte	*complimenten	zijn	vaak	het	leukst.
the$_{SG}$	unexpected$_{SG}$	compliments$_{PL}$	are	often	the	best

Since only *het*-nouns were used as experimental items, in order to prevent the participants from developing a strategy for predicting the (un)grammaticality of sentences, we used 160 filler sentences with the opposite pattern to that of the experimental sentences. The filler items were split evenly between either *de*-nouns (3) or *het*-nouns (4) in order to counterbalance the gender and number conditions of the experimental item sentences, respectively. Hence, participants had to be alert and listen to the entirety of the sentence, not just the article or the adjective, in order to correctly judge the grammaticality of a given sentence.

(3)	Er	ligt	een	rotte	tomaat	in	de	koelkast.
	there	lies	a	rotten$_{C}$	tomato$_{C}$	in	the	fridge

‘There is a rotten tomato in the fridge.’

Er	ligt	een	rot	*tomaat	in	de	koelkast.
there	lies	a	rotten$_{N}$	tomato$_{C}$	in	the	fridge

(4)	Het	oude	paspoort	is	niet	meer	geldig.
	the$_{N.SG}$	old$_{N.SG}$	passport$_{N.SG}$	is	not	anymore	valid

‘The old passport is not valid anymore.’

De	oude	*paspoort	is	niet	meer	geldig.
the$_{C/PL}$	old$_{C/PL}$	passport$_{N.SG}$	is	not	anymore	valid

‘The old passport is not valid anymore.’

The sentences were spoken by a trained female native speaker of Dutch from the Netherlands. Both the grammatical and ungrammatical versions of each sentence were digitally recorded. The final versions of sentences for the study were created by applying a cross-splicing procedure using the Praat software (www.praat.org). The ERP trigger was placed at the onset of the noun.

2.2.4 Procedure

The experiment was created with E-Prime 2.0 (Psychology Software Tools, Inc.). Participants were seated approximately 70-80 cm in front of a computer screen while a continuous electroencephalograph (EEG) was recorded. Participants were instructed to sit in a comfortable position and to avoid excessive movements, in order to minimize muscle or eye movement artefacts. Instructions for the task were then presented on the computer screen for the participant to read. Further oral explanations and examples were offered by the experimenter. Participants were told to listen to sentences for understanding, since they would be required to answer whether some of the sentences (20% of all sentences) were grammatical or not by pressing an appropriate button. The function of the grammaticality judgements was to keep the participants’ attention, as well as to analyze the accuracy of their responses. Before the actual experiment, five practice sentences were presented.

The experiment itself began after the practice items and comprised four blocks, each consisting of 60 sentences (20 experimental and 40 fillers) with a break between each block. Participants were encouraged to take a break after each block. Before each experimental sentence, a white fixation cross appeared on the screen (500 ms), followed by a blank screen during which the sentence was played. After the end of a sentence, the screen would either remain blank or there would be a question mark on the screen lasting for 3 s. The question mark indicated that this was a grammaticality judgement question. Participants had 3 seconds to respond whether a sentence was grammatical or not by pressing the appropriate keyboard button: “p” or “q”. The assignment of the buttons to ‘grammatical’ or ‘ungrammatical’ was counterbalanced throughout the experiment. There were 12 grammaticality judgement questions per block, four of which pertained to the experimental stimuli. Each block took approximately seven minutes and the entire ERP experiment lasted approximately 25 minutes per participant.

2.2.5 EEG Recording and Data Processing

Continuous EEG recording was performed with an EEG cap consisting of 64 scalp electrodes (WaveGuard) using the EEGO-Lab system (ANT Neuro Inc, Enschede, The Netherlands). In addition to the scalp electrodes, one electrode placed above the left eye was used to record and monitor eye blinks and eye movements. Impedances were kept below 10 kΩ. The sampling rate was 500 Hz, with a common average reference.

Offline analysis of the EEG data was conducted with Brain Vision Analyzer 2.0.4 software (Brain Products GmbH, 2012). Data were re-referenced offline to the average of the mastoids and filtered with a band-pass filter with cut-offs at 0.1 Hz and 40 Hz. This was followed by an automatic eye-blink correction. The data were subsequently segmented into epochs consisting of 1700 ms (from 200 ms before the target noun onset until 1500 ms after target onset). Automatic artefact rejection, with a ± 100 µV cut-off, was performed in the interval of -200 ms to 1500 ms for each epoch. Baseline correction was performed relative to the 0-100 ms baseline. The choice of our baseline was based on the visual inspection of the data (including the -200-0 ms interval). We acknowledge that the current baseline is different from the baseline used in Popov (2017), who used the -200-0 ms baseline. However, after a visual inspection, it was necessary to use a different baseline in the current study due to a difference in the pre-stimulus interval between the conditions. We can only speculate that this difference was caused by acoustic effects.[4]

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[4] More specifically, we speculate that this difference between the conditions for adults with dyslexia may have been caused by the presence (ungrammatical gender sentences)/absence (grammatical gender sentences) of the inflection *-e* on the preceding word. This difference was not present in the data of adults without dyslexia (Popov, 2017), and may actually be related to the manner in which participants with dyslexia process inflection.

Lastly, data were averaged per subject and per condition. The cut-off for including participants was at least 70% of averaged trials per condition. Three participants were excluded from the analysis on this account.

2.2.6 Data Analysis

For the EEG analysis, a selection of electrodes (a total of 50) was divided into 9 regions of interest (ROIs), each consisting of 5 to 6 electrodes. Therefore, not all of the 64 scalp electrodes entered the analysis. The regions of interest were as follows: left anterior (F7, F5, F3, FC3, FC5), midline anterior (F1, Fz, F2, FC1, FCz, FC2), right anterior (F4, F6, F8, FC4, FC6), left central (TP7, C5, C3, CP5, CP3), midline central (C1, Cz, C2, CP1, CPz, CP2), right central (C4, C6, CP4, CP6, TP8), left posterior (P7, P5, P3, PO7, PO5, O1), midline posterior (P1, Pz, P2, PO3, POz, PO4), and right posterior (P4, P6, P8, PO6, PO8, O2). Due to a difference in the baseline between the current study and the one by Popov (2017) for adults without dyslexia, the time windows in the current study are also slightly different to the time windows chosen by Popov (2017). The time windows that entered the final analysis for the gender and number conditions in the current study were as follows: 300-500 ms, 500-700 ms, 700-900 ms, 900-1100 ms, 1100-1300 ms and 1300-1500 ms.

Finally, we performed the statistical analysis of the data with a repeated measures Analysis of Variance (ANOVA) separately for each condition. To that end, the following within-subject factors were chosen: grammaticality (two levels: grammatical and ungrammatical), hemisphere (two levels: left and right hemisphere), anteriority (three levels: anterior, central, and posterior), and their interactions. For each time window, two global repeated measures ANOVAs were performed: the first for the lateral regions (including all factors) and the second for the midline regions (excluding the factor hemisphere). The level of significance was set at $p < .05$. Additional follow-up ANOVAs were applied for interactions that were close to significance ($p < .1$) and that included the factor grammaticality. A Greenhouse and Geisser (1959) correction was applied if the assumption of sphericity was violated, and Bonferroni corrections were used for the follow-up pairwise comparisons.

2.3. Results

2.3.1 Grammaticality Accuracy Results

Participants achieved a 84.7% mean accuracy rate on the grammaticality judgement task (range: 75.5% – 93.8%; $SD = 8.5\%$). Since a grammaticality judgement question was present only for 20% of the sentences, no further error analysis was performed.

2.3.2 ERP Results

In this section, we only report the ANOVA results that were significant or close-to-significant. The full ANOVA results, including non-significant ones, can be found in Appendix D.

For adults with dyslexia, a visual inspection of the waveforms indicated a negative effect starting approximately 700 ms after the onset of the stimulus for the number condition only. The effect was present primarily in the anterior regions and was elicited by ungrammatical sentences, relative to grammatical sentences. In addition to the frontal negativity observed in the 700-900 ms time window, another negativity was observed in the 1100-1300 ms time window, also in the number condition. The effect also had an anterior distribution and was elicited by ungrammatical number sentences, relative to grammatical number sentences. No ERP effect was detected for the gender condition.

In the first time window (**300-500 ms**)[5], the ANOVA over lateral ROIs for the number condition yielded a significant interaction between grammaticality and hemisphere ($F(2, 24) = 13.504$, $p = .003$, $\eta^2 = .529$). However, the follow-up *t*-tests of the two-way interaction between grammaticality and hemisphere yielded no significant effects in the lateral regions for the number condition (*p*s > .1).

The ANOVA for the lateral ROIs for the number condition in the second time window (**500-700 ms**) revealed a significant interaction between grammaticality and hemisphere ($F(2, 24) = 5.263$, $p = .041$, $\eta^2 = .305$). However, no significant effects were found in the follow-up tests to the interaction (*p*s > .1).

In the subsequent time window (**700-900 ms**), the ANOVA for the lateral ROIs yielded a close-to-significant effect for grammaticality ($F(1, 12) = 3.684$, $p = .079$, $\eta^2 = .235$) and a significant interaction between grammaticality and anteriority ($F(2, 24) = 8.601$, $p = .004$, $\eta^2 = .418$) in the number condition only. Follow-up testing revealed that ungrammatical number sentences elicited a more negative response than grammatical sentences in the anterior regions ($t(12) = 2.43$, $p = .032$), and were marginally more negative in the central regions ($t(12) = 9.27$, $p = .093$). The ANOVA for the midline ROIs further revealed a significant effect of grammaticality ($F(2, 24) = 5.264$, $p = .041$, $\eta^2 = .305$) and an interaction between grammaticality and anteriority ($F(2, 24) = 9.073$, $p = .006$, $\eta^2 = .431$) for the number condition only. Once again, follow-up tests showed that ungrammatical sentences caused significantly more negative responses relative to grammatical sentences in the anterior regions ($t(12) = 2.71$, $p = .019$), while

[5] We also performed a statistical analysis and visual inspection of the time window before the 300 ms. However, the results of this analysis yielded no significant effects and are, therefore, not reported here (but see Appendix D).

a close-to-significant negative effect for ungrammatical sentences relative to grammatical sentences emerged in the posterior regions ($t(12) = 2.08$, $p = .054$).

No significant effects were found in the **900-1100 ms** time window, for either the gender or the number condition.

The ANOVA performed for the lateral ROIs in the subsequent time window (**1100-1300 ms**) revealed a significant interaction between grammaticality and anteriority ($F(2, 24) = 6.392$, $p = .013$, $\eta^2 = .348$) in the number condition. Follow-up testing showed that the effect was driven by ungrammatical sentences in the anterior regions ($t(12) = 2.59$, $p = .024$). The ANOVA for the midline ROIs also revealed a significant interaction between grammaticality and anteriority ($F(2, 24) = 8.374$, $p = .008$, $\eta^2 = .411$) in the number condition. Follow-up tests showed a main effect of grammaticality in the anterior regions, with ungrammatical sentences being more negative ($t(12) = 2.46$, $p = .03$).

In the last time window (**1300-1500 ms**), the ANOVA for the lateral ROIs yielded a close-to-significant interaction between grammaticality and hemisphere in the number condition ($F(2, 24) = 3.779$, $p = .076$, $\eta^2 = .240$). However, no significant effects for the lateral regions were found in the follow-up tests for the number condition (ps > .1).

2.3.3 Group Comparison of ERP Results

To summarize the ERP results of adults with dyslexia, the statistical analysis revealed that, relative to grammatical sentences, ungrammatical sentences in the number condition elicited a negativity with an anterior distribution in the 700-900 ms time window. The negative effect was absent in the subsequent 900-1100 ms time window, but resurfaced in the 1100-1300 ms time window. The negativity in the 1100-1300 ms time window resembled the one found in the 700-900 ms time window: Ungrammatical sentences in the number condition elicited a negative effect with an anterior distribution relative to grammatical sentences. No statistically significant effects arose for the gender condition in any of the time windows analyzed.

Table 2.2 provides an overview of the ERP responses to gender and number disagreement between adults with dyslexia (current sturdy) and adults without dyslexia (Popov, 2017) to address the first research question.[6] As can be seen, there was a difference in the ERP responses in qualitative terms between the two groups.

[6] The analysis of time windows conducted by Popov (2017) for adults without dyslexia indicated that the onset of the positive effect was earlier in the gender condition (600 ms onwards) than in the number condition (900 ms onwards) due to the difference in the length of the target noun in the gender and number condition – hence the difference in the time windows chosen by Popov (2017).

Table 2.2 Summary of ERP results for adults with dyslexia (current study) and without dyslexia (Popov, 2017).

	Participants with dyslexia		*Participants without dyslexia*			
	GENDER	**NUMBER**	**GENDER**		**NUMBER**	
300-500 ms	x	x	x		x	
500-700 ms	x	x	x		x	
700-900 ms	x	Negativity: anterior regions	**600-800 ms**	LAN: left anterior region P600: posterior midline region	**900-1100 ms**	P600: posterior & right central regions
900-1100 ms	x	x	**800-1000 ms**	LAN: left anterior region P600: posterior regions	**1100-1300 ms**	P600: posterior regions
1100-1300 ms	x	Negativity: anterior regions	**1000-1200 ms**	LAN: left anterior region P600: posterior regions	**1300-1500 ms**	P600: posterior regions
1300-1500 ms	x	x				

Note: x = no effect detected; ms = milliseconds.

Grand mean ERP waveforms comparing brain responses of adults with dyslexia to grammatical and ungrammatical nouns in the gender condition are presented in Figure 2.1, and for the number condition in Figure 2.2.

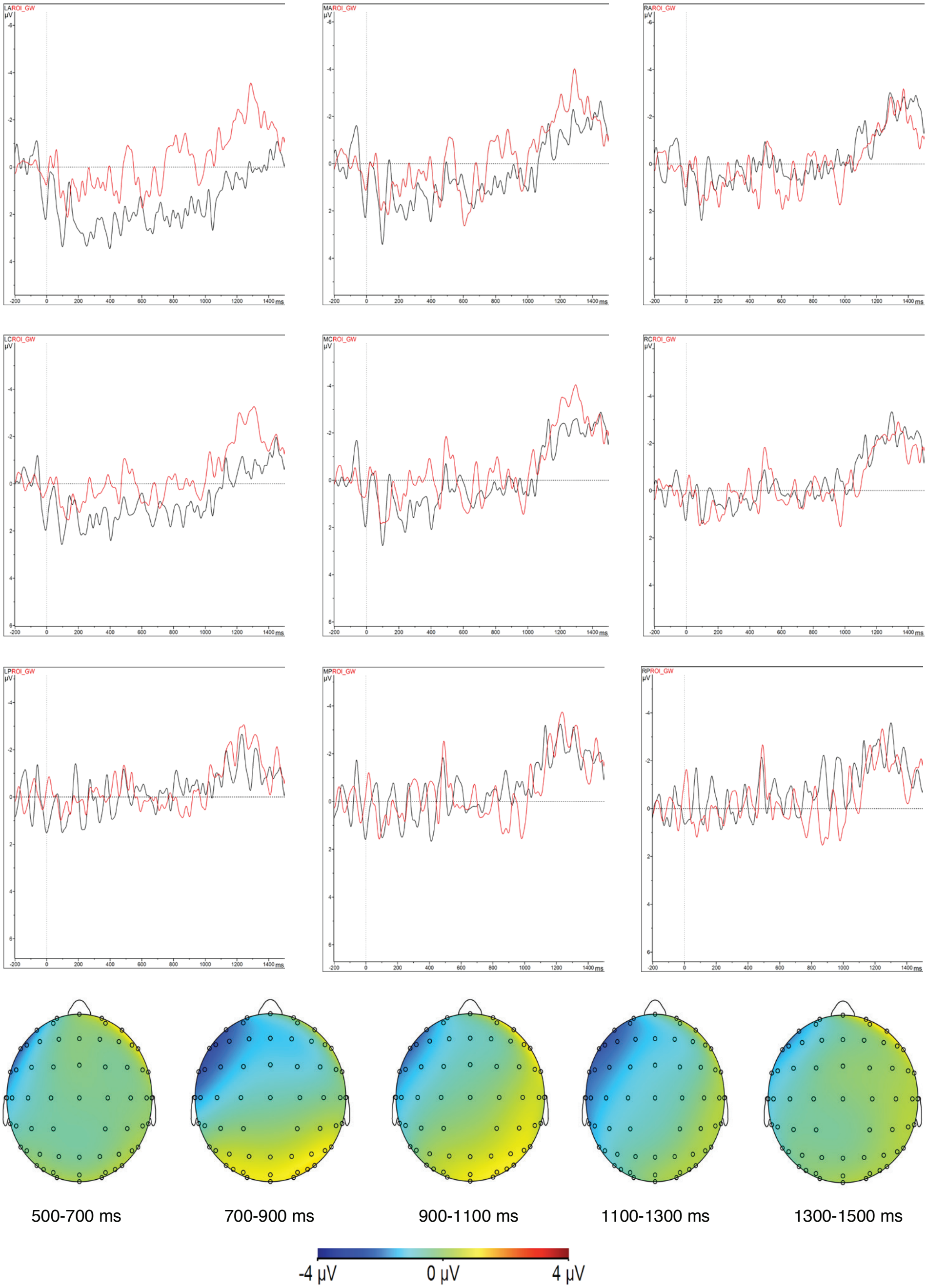

Figure 2.1 Grand average ERPs for the gender condition across all 9 ROIs: black line represents correct sentences and red line represents violated sentences. The topographic maps represent a difference between ungrammatical and grammatical sentences in the different time windows.

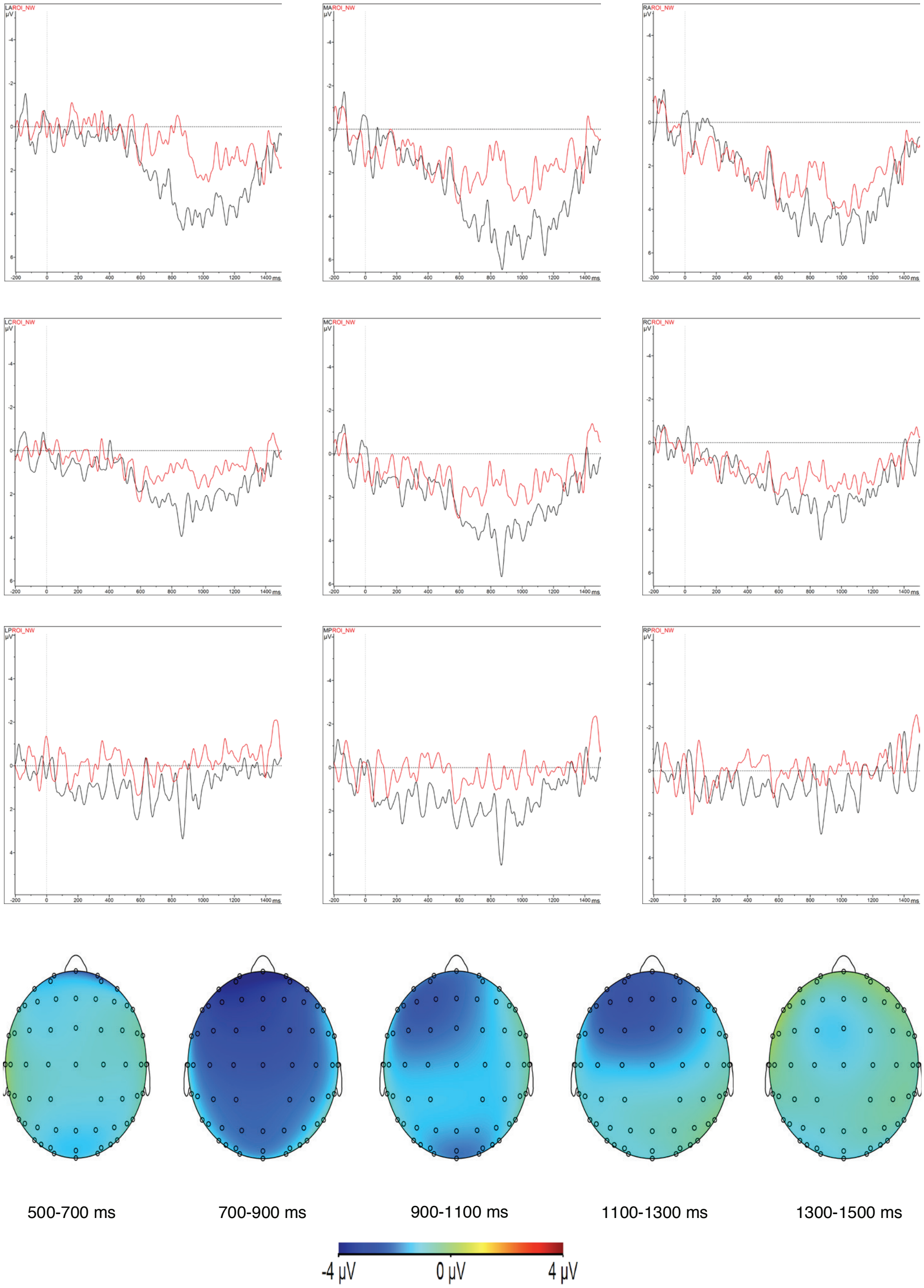

Figure 2.2 Grand average ERPs for the number condition across all 9 ROIs: black line represents correct sentences and red line represents violated sentences. The topographic maps represent a difference between ungrammatical and grammatical sentences in the different time windows.

2.4 Discussion

The current study investigated the processing of morphosyntactic agreement violations in spoken language by adults with dyslexia with the use of both a behavioral grammaticality judgement task and event-related potentials (ERPs). The ERP pattern of adults with dyslexia in response to gender and number disagreement was qualitatively compared to the previously collected data of adults without dyslexia (Popov, 2017). In particular, we examined whether the difference in agreement violation processing between adults with and without dyslexia is reflected by the qualitative and/or topographic differences in the ERP components activated. We also investigated the difference in processing gender and number disagreement in relation to structural repair in adults with dyslexia.

2.4.1 ERP Responses to Morphosyntactic Violations in Listening in Adults with and without Dyslexia

The first conclusion to be drawn from our ERP data is that adults with dyslexia process auditorily presented sentences with an agreement violation differently from adults without dyslexia, as evidenced by the difference in latency and different ERP characteristics. In line with our first research question on the morphosyntactic processing differences between adults with and without dyslexia, we predicted qualitative and/or topographic differences between the two groups, based on previous research (e.g., Cantiani et al., 2013a, 2013b, 2015; Rispens et al., 2006; Rüsseler et al., 2007; Sabisch et al., 2006). Our results are in line with our prediction and previous research, since we found qualitative and temporal differences between adults with and without dyslexia. More precisely, the data of adults with dyslexia show an anomalous ERP pattern consisting of a single ERP component for the number condition only, whereas a classic biphasic LAN-P600 electrophysiological response was present for adults without dyslexia in the gender condition, and a P600 only in the number condition (Popov, 2017). Taking into account the differences in baseline between the groups, we can observe that the onset of the effect in the number condition was delayed in adults with dyslexia than those without dyslexia.[7] Below we will explore group differences per condition.

The absence of an ERP effect in response to **gender disagreement** in adults with dyslexia indicates that they are not sensitive to the violation in the gender condition compared to their peers without dyslexia. Moreover, this finding might

[7] In our summary, we report that the onset of the effect in the number condition started approximately 700 ms after the onset of the target noun in both groups. However, due to the difference in baselines between the groups, we can conclude that the onset of the effect was delayed in participants with dyslexia relative to participants without dyslexia.

indicate that adults with dyslexia possess a different processing strategy for morphosyntactic violations than adults without dyslexia. This discrepancy could have been caused by the nature of the violation in the gender condition, which might have been more subtle for adults with dyslexia to detect than for adults without dyslexia. More precisely, the violation in the gender condition (marked overtly only by the adjectival inflectional marker *-e*) has a low perceptual salience and as such might not be readily detectable by adults with dyslexia. Thus, our ERP results are in line with previous ERP research, which shows that individuals with dyslexia are less sensitive to inflectional morphology, both in reading (e.g., Rüsseler et al., 2007, for gender disagreement) and in listening (e.g., Cantiani et al., 2013a, 2013b; Rispens et al., 2006; for subject-verb disagreement).

For **number disagreement**, the ERP data adults with dyslexia show a puzzling finding of a frontal negativity. This frontal negativity was present in the 700-900 ms and 1100-1300 ms time windows, but was not detectable in the intervening 900-1100 ms time window. We predicted that the number condition in our study would be more perceptually salient than the gender condition, since the violation in the number condition is marked with a lexical and an inflectional morphosyntactic cue. Thus, adults with dyslexia might need additional inflectional cues in order to detect the violation, as in the number condition compared to the gender condition. This suggestion is supported by our results both in the behavioral data, which shows higher accuracy on the grammaticality judgement task for the number condition, and the ERP data, where the ERP effect was only detectable for number disagreement, but not for gender disagreement. One explanation for this ERP pattern in adults with dyslexia is that they employ a *good-enough parsing* strategy (see Ferreira et al., 2002; Ferreira & Patson, 2007). More precisely, adults with dyslexia might rely on a shallow analysis of a sentence and accept an incomplete or incorrect (i.e., 'good-enough') sentence representation, rather than re-analyze the sentence and build a complete and thorough sentence representation upon encountering a violation (as evidenced by the lack of a P600).

Due to its characteristics, there is a possibility that the elicited frontal negativity for number disagreement is a LAN or a LAN-like component, which is typically associated with an automatic detection of a morphosyntactic violation (e.g., Caffarra et al., 2019; Friederici et al., 2002; Molinaro et al., 2014; Popov et al., 2020). Rüsseler et al. (2007) also elicited a frontal negativity in adults with and without dyslexia, but in response to gender disagreement in written word-pairs in German. Previous research shows that anterior negativities are more common in the presence of an additional task, such as the grammaticality judgement task, or explicit task requirements (Osterhout & Mobley, 1995), or in the auditory modality (Hagoort & Brown, 2000). Thus, the presence of an additional task or the modality of presentation might have influenced our results. Although Cantiani et al. (2013a) reported an additional N400-like rather than a LAN-like negativity, the frontal negativity in our study does not resemble an N400(-like) component, given its latency and topography. Regardless of the exact nature of the elicited ERP effect (i.e., whether it is a LAN or another frontal negativity component), its timing coincides with the moment in time in which the agreement error becomes apparent (the disagreeing number inflection on the noun). Therefore, we can say that the negativity is related to error detection, without going into its specific mechanism.

Our results are at odds with previous research (e.g., Cantiani et al., 2013a, 2013b; Rispens et al., 2006), which reported a delayed P600 ERP effect in adults with dyslexia in response to sentences containing subject-verb disagreement. Our data also contradict the finding of a general slower processing in adults with dyslexia elicited for other electrophysiological components (e.g., Breznitz & Leikin, 2000). Still, we cannot completely disregard the idea that the dyslexia group indeed showed slower processing. The negative component may have just indicated the recognition of the violation, while the other processes, such as repair and reanalysis, took place after the recognition and at a later point which we did not include in the analysis.

The finding of a different ERP component for adults with dyslexia relative to adults without dyslexia in our study is somewhat similar to previous ERP research on adults with dyslexia that reported a divergent ERP pattern between the two groups (Cantiani et al., 2013a, 2013b). Thus, Cantiani and colleagues (2013a, 2013b) reported a monophasic ERP pattern for adults without dyslexia and a biphasic ERP pattern for adults with dyslexia (i.e., an N400-like component and a P600: Cantiani et al., 2013a; an Early Negativity and an additional P600-like positivity: Cantiani et al., 2013b) in response to subject-verb disagreement in listening. Notably, Cantiani et al. (2013a) interpreted the finding of an additional ‘N400-like’ component in adults with dyslexia in light of the ERP literature on L2 learners. The N400-like component is not typically elicited in classical studies on agreement processing (see Molinaro et al., 2011, for a review), but similar ERP activation in response to morphosyntactic violations has been reported in different stages of L2 learning depending on one’s proficiency in L2 (see Steinhauer et al., 2009, for a review). Akin to Cantiani et al. (2013a), we can interpret our finding of a frontal negativity in adults with dyslexia in light of ERP literature on L2 processing (e.g., Steinhauer et al., 2009). More specifically, both the LAN and the N400 have been reported in studies on near-native or native-like L2 learners, oftentimes accompanying the P600 in response to morphosyntactic violations. Thus, the frontal (LAN-like) negativity in our study could represent a reliance on a compensatory cognitive or linguistic mechanism due to insufficient mastery in constructing implicit morphosyntactic rules. This interpretation is further supported by the lack of a P600.

Steinhauer et al. (2009) further argue that it is not only proficiency, but also a delay in the L2 acquisition that influences the mechanism underlying syntactic processing. In their review, they provide evidence that the distribution, amplitude and latency of both the LAN and the P600 in L2 learners is influenced by late L2 acquisition. For instance, late learners (i.e.., age of acquisition over 16 years of age) exhibit a bilateral or right distribution of the anterior negativity, while early L2 learners (i.e., acquired L2 by the age of 11) exhibit a more typical, native-like left lateralized negativity (the LAN) in response to phrase structure violations in the L2. These findings for L2 learners resemble the hypothesis which posits that morphosyntactic processing difficulties in dyslexia are a result of a delay in grammatical acquisition, caused by reduced reading experience compared to typical readers (see Chapter 1, Section 1.4). However, we did not test whether reading experience influences the characteristics of ERP components, or the existence of morphosyntactic processing difficulties in adults with dyslexia. Therefore, this remains a topic for future research. Finally, the ERP pattern of adults with dyslexia that resembles the ERP pattern of L2 learners can be construed as support for Byrne's (1981) claim that individuals with dyslexia function at an overall lower or less mature level of linguistic processing, somewhat comparable to the near-native processing of highly proficient L2 learners, as revealed by ERPs.

The discrepancy between the findings of our study and previous ERP research on morphosyntactic processing in adults with dyslexia could alternatively be explained by methodological reasons related to the stimuli, as well as the population size. While most studies used subject-verb agreement to investigate morphosyntactic processing in adults with dyslexia using ERPs (Cantiani et al., 2013a, 2013; Rispens et al., 2006), we used sentences containing gender and number disagreement. Thus, our stimuli might contain inflectional cues that are more subtle for adults with dyslexia to detect and the detection of these cues does not always show in the ERP signal. However, it is also crucial to mention that the results of the current study need to be interpreted with caution due to the limitations regarding the small sample size. Therefore, a larger sample size is required in order to more convincingly establish whether there is a more robust and typical ERP effect (e.g., the P600) in response to gender and number disagreement in listening in adults with dyslexia. Furthermore, we acknowledge that the choice of our baseline and time windows were slightly different to those of Popov (2017) and were based on visual inspection, due to the nature of our data. However, that should not have caused a significant difference in our results.

2.4.2 ERP Differences between Gender and Number Disagreement Processing in Adults with Dyslexia

To answer our second research question, we focused on the difference in the ERP results of adults with dyslexia in the gender and number conditions. In line with our prediction, we did notice an ERP processing asymmetry between listening to sentences with gender disagreement compared to sentences with number disagreement in the group with dyslexia. While no ERP effect was detected in the gender condition, a frontal negativity described earlier (present in the 700-900 ms and 1100-1300 ms time windows) was elicited in response to ungrammatical sentences in the number condition.

The most plausible explanation for the discrepancy between the two conditions lies in the difference between the structures under investigation. We predicted that adults with dyslexia will have more difficulty detecting the violation in the gender compared to the number condition due to the difference in perceptual salience between the conditions. Since individuals with dyslexia are less sensitive to inflectional morphology (e.g., Casalis et al., 2013; Rispens et al., 2004, 2006), it could be that they require more inflectional cues in order to detect a violation in ungrammatical sentences and for an ERP effect to be visible (like in our number condition). In our study, when listening to ungrammatical sentences in the gender condition, the violation could only be detected by noticing the presence of a subtle inflectional cue (i.e., the adjectival suffix *-e* preceding the target noun; e.g., **een diepe meer*). Thus, the violation in the gender condition might not only be less perceptually salient, but could also be more subtle for adults with dyslexia to detect in listening using ERPs.

Ultimately, our data do not allow us to draw a conclusion regarding the structural repair mechanism underlying gender and number disagreement, since the stimuli in our study did not elicit the P600, an ERP component associated with repair and reanalysis processes in agreement studies (e.g., Molinaro et al., 2011; Popov & Bastiaanse, 2018). This is the first ERP study that has investigated structural repair mechanisms in dyslexia. Therefore, more research is needed to disentangle the exact processes underlying structural repair mechanisms in dyslexia with ERPs.

2.5 Conclusion

The current study investigated the behavioral and event-related potential (ERP) responses of Dutch adults with dyslexia to auditorily presented sentences containing a morphosyntactic agreement violation (i.e., gender or number disagreement). The results were compared to those of adults without dyslexia from a previous study (Popov, 2017). A difference in processing was visible both at the behavioral level and at the level of ERPs. Adults with dyslexia performed more poorly relative to adults without dyslexia on the behavioral grammaticality judgement task. Moreover, whereas no ERP effect was observed in adults with dyslexia for sentences containing gender disagreement, a frontal negativity emerged in response to sentences containing number disagreement. The puzzling finding of the frontal negativity in response to number disagreement in our study can be explained as a potential LAN-like component, reflecting violation detection, or as a mechanism that adults with dyslexia use in order to compensate for underdeveloped morphosyntactic skills. Thus, adults with dyslexia were less sensitive to sentences with gender disagreement, both at the behavioral and ERP level. Although a small sample size limits the generalizability of our results, this study still highlights the use of ERPs as a sensitive measure of morphosyntactic processing differences between adults with and without dyslexia. The question that remains, and which will be explored in the next chapter, is to what extent are the results in the current chapter influenced by listening as the presentation modality and whether the same ERP effects will be visible in a reading study using the same stimuli.

CHAPTER 3

Processing Gender and Number (Dis)agreement in Adults with Dyslexia in Reading and Listening: An Event-Related Potential (ERP) study

3.1 Introduction

As mentioned in Chapter 1, questions on the underlying cause of dyslexia have been the topic of research since the early descriptions of this impairment in the 19th century. Over the years, a multitude of theories have emerged attempting to account for the behavioral symptoms observed in dyslexia. Broadly speaking, the majority of these theories can be classified into those linking the behavioral characteristics of dyslexia to an underlying impairment in the visual (e.g., Valdois et al., 2004, for a review of evidence) or auditory domain (e.g., *Rapid Auditory Processing Theory* by Tallal, 1980). However, none of the single-cause theories of dyslexia adequately explains all the behavioral symptoms and a multiple cognitive deficit model of dyslexia is now widely accepted (e.g., Pennington, 2006). Nevertheless, it is important to recognize that both auditory impairments and visual word recognition impairments feature prominently in dyslexia research. Thus, those authors who have conducted behavioral studies on morphosyntax have found that children and adults with dyslexia display difficulties in both production (e.g., Altmann et al., 2008; Joanisse et al., 2000; Robertson et al., 2013; Wiseheart & Altmann, 2018) and comprehension (e.g., Rispens et al., 2004; Robertson & Joanisse, 2010) of morphosyntactic constructions. These comprehension difficulties were observed both in the written (e.g., Jiménez et al., 2004; Stella & Engelhardt, 2019; Wiseheart et al., 2009) and auditory domains (e.g., Rispens et al., 2004; Robertson et al., 2013; Waltzman & Cairns, 2000). Furthermore, adults with dyslexia have been found to perform more poorly than typical readers on detecting errors in written words and sentences (Horowitz-Kraus & Breznitz, 2011). Similarly, difficulties with auditory syntactic error detection and sentence correction have also been reported in individuals with dyslexia (children: Chung et al., 2014; Leikin & Assayag-Bouskila, 2004). Although the role of the presentation modality seems to be an important one, only a few behavioral studies on morphosyntactic processing directly compared the performance of individuals with dyslexia on written and auditory stimuli presentation (e.g., Antón-Méndez et al., 2019; Casalis et al., 2013). Therefore, in order to disentangle the role of the presentation modality in individuals with dyslexia, we ran the study described in the previous chapter both as a listening experiment and a reading one.

When it comes to studies on morphosyntactic processing in dyslexia using event-related potentials (ERPs), previous research with both children and adults with dyslexia has focused on the auditory modality (e.g., Cantiani et al., 2013a, 2013b, 2015; Rispens et al., 2006; Sabisch et al., 2006), most likely in order to control for reading difficulties as a potential confound. The few ERP studies that have explored morphosyntactic processing in dyslexia in reading (e.g., Miller-Shaul, 2005; Rüsseler et al., 2007) have not focused on sentences, but on word pairs, which are known to elicit a different ERP pattern to sentence-level processing. So far, no study has directly compared the ERP patterns in both reading and listening using sentences with morphosyntactic violations.

In this chapter, we describe a reading ERP study on gender and number disagreement conducted on Dutch adults with dyslexia. Gender in Dutch is known to cause difficulties for both typical and atypical populations (e.g., individuals with aphasia: Bastiaanse et al., 2003; monolingual Dutch children: Blom et al., 2008; second language speakers and children with developmental language disorders: Orgassa, 2009). Consequently, we included gender disagreement to ensure that the stimuli used were sufficiently complex and challenging to tap into potential difficulties in morphosyntactic skills in dyslexia (following Shankweiler et al., 1995). This is especially pertinent for adults with dyslexia, who frequently have undergone extensive remediation and/or developed strategies to overcome reading difficulties, including difficulties in the domain of morphology (Casalis et al., 2004; Elbro & Arnbak, 1996). By using the same stimuli, we are able to compare the results of adults with dyslexia in the current study to the results of a reading study by Popov and Bastiaanse (2018) on Dutch adults without dyslexia. Finally, we discuss the results of the current study conducted in the visual modality in relation to the results of the ERP study from Chapter 2 conducted on a different group of adults with dyslexia with the same materials in the auditory modality. Our overarching goal was to examine gender and number disagreement processing in both the visual and the auditory modality. By doing so, we hope to eliminate potential limitations on conclusions from conducting an ERP study on individuals with dyslexia in only one presentation modality, and to explore the mechanisms of morphosyntactic processing for both modalities.

3.1.1 Reading vs. Listening in Language Studies in Dyslexia

Regardless of the modality or method used, previous studies have identified morphosyntactic processing difficulties in both children and adults with dyslexia in the domain of (morpho)syntax. Thus, individuals with dyslexia have been found to exhibit difficulties with different (morpho)syntactic structures in the comprehension of both written (e.g., Jiménez et al., 2004; Miller-Shaul, 2005; Rüsseler et al., 2007; Stella & Engelhardt, 2019; Wiseheart et al., 2009) and spoken language (e.g., Cantiani et al., 2013a, 2013b, 2015; Joanisse et al., 2000; Leikin & Assayag-Bouskila, 2004; Rispens et al., 2004, 2006; Robertson & Gallant, 2019; Robertson & Joanisse, 2010; Robertson et al., 2013; Sabisch et al., 2006; Waltzman & Cairns, 2000).

However, several behavioral (morpho)syntactic studies have aimed to provide an answer to the question of which presentation modality (auditory vs. written) is more taxing for individuals with dyslexia. Casalis et al. (2013) examined syntactic comprehension in children with dyslexia in both reading and listening. They found that syntax posed a particular difficulty for children with dyslexia compared to reading age-matched children, but only in the written, and not in the spoken modality. Namely, children with dyslexia performed more poorly on morphosyntactic tasks (i.e., a receptive grammar task and a relative clause processing task) than reading age-matched children while reading sentences, but their performance was comparable to typical readers while listening to sentences. The authors found that children with dyslexia were ‘insensitive’ to inflectional markers in complex syntactic structures in both the visual and auditory modality. However, this was also the case for the reading-age control group, whereas the children in the age-matched typically reading control group were the only children who showed sensitivity to inflectional markers that support syntactic comprehension.

In contrast, Antón-Méndez et al. (2019) found no effect of presentation modality on the production of subject-verb agreement attraction errors in Spanish children with dyslexia. Children with dyslexia produced the same number of production errors, regardless of whether the elicitation preamble (i.e., the beginning of the sentence used to elicit a response) was written or spoken. A study by Raveh and Schiff (2008) examined morphological priming in Hebrew-speaking university students with dyslexia. Morphological difficulties were present in adults with dyslexia on tasks reflecting automatic visual word-recognition, but not on tasks associated with auditory word-recognition processes. In summary, only a handful of behavioral studies directly investigated the influence of presentation modality on the performance of individuals with dyslexia on morphosyntactic processing tasks and found conflicting results (no influence of presentation modality: Antón-Méndez et al., 2019; Casalis et al., 2013; worse performance on written than auditory modality: Raveh & Schiff, 2008).

3.1.2 The Role of Presentation Modality in ERP Research

Relatively few ERP studies have directly compared the modality of presentation (visual vs. auditory) in sentence processing with unimpaired participants (but see, Balconi & Pozzoli, 2005; Hagoort & Brown, 2000; Meulman et al., 2014; Popov, 2017). Instead, most studies on sentence processing in general, and agreement processing in particular, have focused on reading rather than listening (Molinaro et al., 2011). While presenting stimuli word-by-word on the screen in the written modality enables very precise stimulus time-locking (e.g., to a particular word in a sentence) and a more straightforward experimental design, this presentation modality does have the disadvantage of being an artificial and somewhat unnatural mode of reading. In contrast, auditory stimulus presentation allows for a more ecologically valid design due to a more natural manner of presenting sentences, since participants hear sentences spoken in real time. However, the main drawback of auditory stimulus presentation is that it allows for greater ERP component overlap, since natural speech does not contain pre-programmed pauses between words and as such, natural speech cannot be controlled in the same manner as reading ERP experiments.

If we assume that listening and reading rely on the same syntactic processing mechanism, then we should expect the same ERP components to be elicited in both modalities (following Friederici, 1996). As mentioned in the previous chapter, the P600 is an ERP component typically associated with morphosyntactic repair and reanalysis, as well as difficulties with morphosyntactic integration in agreement studies (e.g., Friederici, 2002; Friederici et al., 1993; Kutas & Hillyard, 1980; Molinaro et al., 2011; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995; Popov & Bastiaanse, 2018; Popov et al., 2020). Meanwhile in agreement studies, if elicited, the LAN, or left-anterior negativity, a component that precedes the P600, is thought to reflect early and automatic violation detection (see Molinaro et al., 2014). The studies that have compared presentation modality for the same stimuli have reported either slight differences in the ERP response (e.g., Hagoort & Brown, 2000; Popov, 2017) or no differences (e.g., Balconi & Pozzoli, 2005; Meulman et al., 2014) to reading versus listening to sentences with morphosyntactic violation. Hagoort and Brown (2000) found no (major) differences in the time course of reading and listening to the same sentences in Dutch with regards to the P600. However, they reported a difference in the elicitation of the LAN for the same stimuli: the LAN was found only for auditory and not for written stimuli presentation, and in only two out of three conditions of the auditory modality.

Popov (2017) also reported differences in the time course of ERP components depending on the modality of presentation in both Italian and Dutch. In two studies on syntactic and semantic gender disagreement processing in Italian, Popov (2017) elicited the LAN and the P600 in both reading and listening, with a slightly different topographic distribution between the conditions. However, the LAN was absent in the semantic gender condition in listening. Investigating the processing of grammatical gender and number disagreement in Dutch, he reported a LAN only in the auditory modality for gender disagreement, in contrast to Hagoort & Brown (2000). Meanwhile, a P600 was elicited both in the auditory (number disagreement) and the written modality (both conditions), although the topographic distribution was slightly different between the conditions. Furthermore, the ERP effects seemed to have a larger amplitude and broader distribution in reading than in listening. Therefore, Popov (2017) concluded that the mode of presentation plays a role in agreement violation processing in adults without dyslexia using ERPs.

An important point worth bearing in mind is the difference in the time course of the elicited components between reading and listening in typical readers, which is related to the difference in the speed of delivering information between spoken and written language. Both speech perception and language processing during reading are rapid and incremental processes (Rayner & Clifton, 2009). However, a typical speaking rate is 120-200 words per minute – somewhat slower than the reading speed of skilled readers, which is 250-350 words per minute (Rayner & Clifton, 2009). As demonstrated by Popov (2017), this difference between word recognition in reading and listening leads to a delay in the onset of the ERP effect in listening compared to reading. More specifically, when a word is spoken, it takes approximately 200 ms longer to notice an agreement violation in listening than in reading due to the faster speed of visual than speech recognition. Therefore, we also expect to see a difference in the time course of the ERP components between different presentation modalities for adults with dyslexia.

3.1.3 Current Study

The present study investigated the morphosyntactic processing of gender and number disagreement in Dutch adults with dyslexia by means of an ERP sentence-reading paradigm. Similar to Wiseheart et al. (2009), we aim to minimize the potential confounds of reading experience and comorbid language impairments by investigating morphosyntactic processing in high-performing university students with dyslexia (high-performing, because they were attending university: Parrila et al., 2007), who are less likely to be affected by diminished reading experience (Raveh & Schiff, 2008).

Behavioral and ERP results for adults without dyslexia were collected and reported by Popov and Bastiaanse (2018) using the same paradigm and materials. We will be comparing our results qualitatively against theirs in a visual descriptive comparison, which will look into the difference in the latency and the distribution of the ERP effects in the two groups.[8]

At present, it is not known how individuals with dyslexia process sentences containing morphosyntactic violations in reading compared to listening. We therefore compared the results of the current reading study to those of the listening

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8 We will not compare the effects in the two groups directly, because we are interested in the onset, rather than the effect size of the effect (i.e., primarily the P600). One of the major reasons that we are not interested in the P600 effect size is that we expect the components to have a different onset in the two groups, which renders the results of the comparison uninterpretable.

study in Chapter 2 conducted with the same stimuli. By doing so, we were able to compare the two presentation modalities with respect to the presence/absence of ERP components, as well as their topographic and temporal characteristics. To summarize, the ERP results of the listening study from Chapter 2 show no effect for the gender condition and a frontal negativity for the number condition in adults with dyslexia.

We also aimed to examine the complexity of structural repair processes in gender and number disagreement in reading, which would be reflected in a processing discrepancy between these two types of constructions in the late stage of the P600 (e.g., Barber & Carreiras, 2005; Popov & Bastiaanse, 2018). As explained in more detail in Chapter 2 (Section 2.1.1), gender disagreement in the current study only had one structural repair option (i.e., *een mooie*$_{C(ommon)}$ *dorp*$_{N(euter)}$ > *een mooi*$_{N}$ *dorp*$_{N}$), while the number condition contained two potential repair options (i.e., **het*$_{SG}$ *mooie*$_{SG/PL}$ *dorpen*$_{PL}$ > *het*$_{SG}$ *mooie* $_{SG}$ *dorp*$_{SG}$; **het*$_{SG}$ *mooie*$_{SG/PL}$ *dorpen*$_{PL}$ > *de*$_{PL}$ *mooie*$_{PL}$ *dorpen*$_{PL}$). In Popov & Bastiaanse's (2018) study on adults without dyslexia, more reanalysis options for number disagreement were assumed to require more complex structural repair and, as a result, elicited a larger P600 effect, especially in the late stage of the P600, for number than gender disagreement. Thus, if there is a difference in structural repair between gender and number in adults with dyslexia, we expect to see a difference between the two conditions in the elicitation of the P600 component, especially in the late stages of the P600.

3.1.3.1 Research Questions and Predictions

We formulated the following research questions for the ERP study:

Research Question 1: Is there a difference in the processing of agreement violations in written stimuli between adults with and without dyslexia, as reflected in their ERP responses to gender disagreement and number disagreement when qualitatively comparing the latency and the distribution of those ERP effects?

Prediction 1: Based on previous studies (e.g., Cantiani et al., 2013a, 2013b; Rispens et al., 2006), we predict that there will be a difference in processing these violations, as well as a general difference in ERP processing, between adults with dyslexia (current study) and adults without dyslexia (Popov & Bastiaanse, 2018), reflected by qualitative and/or topographic differences in ERP responses between the two groups. In general, we expect to elicit a P600 (in line with Cantiani et al., 2013a, 2013b; Rispens et al., 2006) for adults with dyslexia. We do not have a firm prediction regarding the elicitation of the LAN.

Research Question 2: In the group of adults with dyslexia, is there a difference in the ERP responses between the two conditions (i.e., number and gender disagreement)?

Prediction 2: We do not have a prediction on the difference in the ERP responses to gender and number violations in adults with dyslexia, due to a lack of literature on the topic, as well as the inconclusive results on the structural repair mechanism (i.e., the lack of a P600) in our listening study from Chapter 2.

Research Question 3: Is there a difference in the presentation modality (listening, Chapter 2 vs. reading, current study) for adults with dyslexia as measured by ERPs?

Prediction 3: We predict that presentation modality will play a role in the performance on adults with dyslexia. As mentioned in Section 3.1.2, we expect to see a difference in the time course of the ERP components between different presentation modalities for adults with dyslexia, due to a faster speed of written than spoken word recognition. However, we do not have a firm prediction regarding the differences in ERP effects between reading and listening to the same sentences in adults with dyslexia, since no previous research compared the two modalities in dyslexia using ERPs.

3.2 Method

3.2.1 Participants

A total of 24 participants with dyslexia who did not take part in the listening experiment were recruited. Data from one participant with dyslexia were excluded due to excessive errors in the grammaticality judgement task (i.e., 80% incorrect responses), leaving a total of 23 participants (7 male; mean age 22,4; age range 18-30).

All participants were diagnosed as having clinical dyslexia prior to the experiment and had a valid statement of their dyslexia diagnosis. Participants also reported no other linguistic impairment (e.g., no history of speech therapy) apart from dyslexia, as confirmed by the intake questionnaire. The diagnosis criteria followed in this study were those of the Dutch Dyslexia Foundation (SDN et al., 2016). Dyslexia diagnosis was confirmed through a questionnaire and the use of selected behavioral tasks (see below).

Additionally, all participants satisfied the following inclusion and exclusion criteria: native speakers of Dutch from The Netherlands, right-handed (as assessed by a Dutch adaptation of the Edinburgh Handedness Questionnaire; Oldfield, 1971), at least 18 years old, normal or corrected-to-normal vision, no hearing impairments, and no history of neurological or psychiatric disorders (e.g., epilepsy, Attention Deficit Disorder (ADD), or Autism Spectrum Disorders (ASD)).

Written informed consent was obtained from all participants prior to the experiment, and after having received written and verbal information about the study. All participants received financial compensation of 15 EUR for taking part in the study. The experiment was approved by the local ethics committee (Research Ethics Committee (CETO), Faculty of Arts, University of Groningen).

3.2.2 Behavioral Measures

At the beginning of the study, a set of short behavioral measures was administered in order to confirm the dyslexia diagnosis, since we could not control how the participants' dyslexia was initially diagnosed. The tests were selected based on the short protocol for dyslexia assessment (Tops et al., 2012). For diagnosing dyslexia, Tops et al. (2012) found support for the reliability and validity of selected number of tests from a comprehensive assessment battery for dyslexia diagnosis in Dutch (Test voor Gevorderd Lezen en SCHrijven – GL&SCHR; De Pessemier & Andries, 2009). We assessed word reading fluency (One Minute Test; Tops et al., 2019), pseudo-word reading fluency (The Klepel; Van den Bos et al., 1994), and word spelling (spelling subtest of the GL&SCHR) to confirm the dyslexia diagnosis. An additional test tapping into phonological awareness ('Reversals', GL&SCHR), as well as morphological and syntactic knowledge (morphology and syntax subtest of the GL&SCHR) were administered. These tests are described in Appendix A.

The scores of participants with dyslexia on the behavioral tests are shown in Table 3.1. Participants with dyslexia displayed either a clinical (< *Pc* 10) or subclinical (< *Pc* 16) score on word reading fluency and pseudo-word reading fluency, and/or spelling to dictation, thus confirming the dyslexia diagnosis.

Table 3.1 Mean percentile scores of the 23 participants with dyslexia on the behavioral tests compared to normative data.

	Mean Pc score	*SD*
Dyslexia diagnostic tests		
Word reading fluency	5.3	2.8
Pseudo-word reading fluency	3.6	2.7
Spelling to dictation	5.9	5.4
Other dyslexia tests		
Reversals	13.9	13.7
Morphology & syntax	37.5	27

Note: *Pc* = percentile, *SD* = standard deviation.

3.2.3 Materials

The materials used in the experiment are those used by Popov and Bastiaanse (2018) and used in Chapter 2, with the only difference being that we used both monosyllabic and trisyllabic words as experimental items in the current study, while in the listening experiment in Chapter 2, we only used trisyllabic words, due to the difference in duration between the two types of nouns in listening. We present details again here for the convenience of the reader. Full materials can be found in Appendix B.

The materials comprised 320 experimental sentences and 160 fillers. The materials were constructed with the use of 80 unique Dutch nouns, 40 of which were neuter (*het*) nouns and 40 common gender (*de*) nouns. Only *het*-nouns were used as experimental stimuli, with *de*-nouns included as fillers. Half of the nouns used for the experimental sentences were monosyllabic and half trisyllabic, while fillers always comprised disyllabic nouns. The nouns were further controlled for animacy (only inanimate nouns were used), noun-verb homophony (i.e., no nouns were used that could be homophonous to the infinitive form of the verb, e.g., *boek* 'book' > *boeken* 'books $_{Noun/}$'/'to book $_{Verb}$') and phonological alternations (e.g., irregular plurals, such as *kind* 'child' – *kinderen* 'children', were excluded).

For the experimental items, each noun was used to construct four sentences, with each sentence being used once as grammatical and once as ungrammatical. This means that each participant read 160 experimental sentences in total (40 gender grammatical, 40 gender ungrammatical, 40 number grammatical, 40 number ungrammatical), which were then divided into two lists (80 grammatical (40 gender, 40 number) and 80 ungrammatical (40 gender, 40 number) and 80 filler sentences). If a grammatical sentence was in List 1, an ungrammatical version of the same sentence was in List 2 and vice versa. Each participant was exposed to only one list. Sentences were presented in a pseudo-random order.

The agreement mismatch in the gender condition was created by a gender mismatch between the adjective and the noun, which created a violation that the parser could recognize only at the end of the target noun (see example 1). In the number condition, the agreement mismatch was created by a number mismatch between the article and the noun and the violation itself could only be recognized once the parser reached the target noun (e.g., example 2).

GENDER CONDITION:

(1)	Er	lag	een	mooi	dorp	vlakbij	de	grote	stad.
	there	lay	a	beautiful$_N$	village$_N$	near	the	big	city

'A beautiful village was close to the big city.'

	Er	lag	een	mooie	*dorp	vlakbij	de	grote	stad.
	there	lay	a	beautiful$_C$	*village$_N$	near	the	big	city

NUMBER CONDITION:

(2)	De	gezellige	dorpen	trekken	veel	toeristen	in	de	zomer.
	the$_{PL}$	nice$_{PL}$	villages$_{PL}$	attract	many	tourists	in	the	summer

‘The nice villages attract many tourists in the summer.’

Het	gezellige	*dorpen	trekken	veel	toeristen	in	de	zomer.
the$_{SG}$	nice$_{SG}$	*villages$_{PL}$	attract	many	tourists	in	the	summer

In order to prevent the participants from developing a strategy for predicting the (un)grammaticality of sentences, 160 filler sentences were used with an opposite pattern to that of the experimental sentences. The filler items were split evenly between either *de*-nouns (3) or *het*-nouns (4) in order to counterbalance the gender and number conditions of the experimental item sentences, respectively. Hence, participants had to be alert and read the entire sentence, not just the article or the adjective, in order to correctly judge the grammaticality of a given sentence.

(3)	Er	ligt	een	rotte	tomaat	in	de	koelkast.
	there	lies	a	rotten$_{C}$	tomato$_{C}$	in	the	fridge

‘There is a rotten tomato in the fridge.’

Er	ligt	een	rot	*tomaat	in	de	koelkast.
there	lies	a	rotten$_{N}$	*tomato$_{C}$	in	the	fridge

(4)	Het	oude	paspoort	is	niet	meer	geldig.
	the$_{N.SG}$	old$_{N.SG}$	passport$_{N.SG}$	is	not	anymore	valid

‘The old passport is not valid anymore.’

De	oude	paspoort	is	niet	meer	geldig.
the$_{C/PL}$	old$_{C/PL}$	*passport$_{N.SG}$	is	not	anymore	valid

3.2.4 Procedure

The order of the experimental sentences and fillers was pseudo-randomized and presented with E-Prime 2.0 (Psychology Software Tools, Inc.) word by word on a computer screen on a black background in white font (font type: Arial, size: 24 pt.). Each sentence was presented only once. Before each experimental sentence, a fixation cross appeared on the screen (500 ms), followed by a blank screen (200 ms). Each word of the sentence was displayed in the middle of the screen for 400 ms, followed by a blank screen for 200 ms as a break between words. Hence, the total interstimulus interval (the difference in time between the onsets of two words) was 600 ms. Each final word in a sentence included a full stop and was followed by a blank screen of 500 ms, indicating a sentence break.

Participants were seated in front of a computer screen at approximately 70-80 cm distance while a continuous electroencephalograph (EEG) was recorded. Participants were instructed to sit in a comfortable position and to avoid excessive movements, in order to minimize subsequent muscle or eye movement artefacts. The experimenter first explained the task and provided examples in order to ensure that the participants understood what they were required to do. They were told to read sentences from the screen for comprehension, as they would be required to answer whether some of the sentences (20% of all sentences[9]) were grammatical or not by pressing an appropriate button. The function of the grammaticality judgements was to keep the participants' attention, as well as to analyze the accuracy of their responses. Instructions for the task were then presented on the computer screen for the participant to read. Further explanations and examples were offered by the experimenter where necessary. Before the actual experiment, 5 practice sentences were presented. The experiment itself comprised 4 blocks, each consisting of 60 sentences (20 experimental and 40 fillers) with a break between each block. Participants were encouraged to take a break after each block. There were 12 grammaticality judgement questions per block, 4 of which pertained to the experimental stimuli. If a grammaticality judgment was required after a given sentence, a question mark would appear on the black screen after the given sentence (i.e., after the 500 ms sentence break). Participants had 3 seconds to respond whether a sentence was grammatical or not by pressing the appropriate keyboard button: "p" or "q". The assignment of the buttons was counterbalanced throughout the experiment. Each block took approximately 7 minutes and the entire ERP experiment lasted approximately 25-30 minutes.

3.2.5 EEG Recording and Data Processing

For the recording, we used an EEG cap consisting of 64 scalp electrodes (WaveGuard; ANT Neuro Inc., Enschede, The Netherlands). The electrodes were positioned in an extended 10-20 system. Horizontal eye movements were recorded via a bipolar eye electrode (HEOG) placed at the outer canthus of each eye. Vertical eye movements were recorded via a bipolar eye electrode (VEOG)

[9] A grammaticality judgement question was present only for 20% of the sentences in the experiment, since we wanted to make the current study as similar as possible to the original study on adults without dyslexia by Popov and Bastiaanse (2018).

positioned below and above the left eye. Impedances were kept below 10 kΩ, and in most cases under 5 kΩ. The sampling rate was 512 Hz, with a common average reference.

Offline analysis of the EEG data was conducted using Brain Vision Analyzer 2.0.4 software (Brain Products GmbH, 2012). The data were first downsampled to a 256 Hz sampling rate and then re-referenced offline to the average of the mastoids. The data were filtered with a band-pass filter with cut-offs at 0.1 Hz and 40 Hz. This was followed by an automatic eye-blink correction. The data were subsequently segmented into epochs consisting of 1400 ms (from 200 ms before the target word and lasting until 1200 ms after target onset). Automatic artefact rejection, with a ± 100 µV cut-off, was performed for each epoch. A standard pre-stimulus baseline correction was also performed for each epoch, starting 100 ms before the target word (- 100-0 ms stimulus onset). Lastly, data were averaged per subject and per condition. The data of participants that had fewer than 70% of averaged trials in one or more conditions were excluded from the analysis.

3.2.6 Data Analysis

For the ERP analysis, a selection of electrodes (a total of 50) was divided into 9 regions of interest (ROIs), each consisting of 5 to 6 electrodes. Therefore, not all of the 64 scalp electrodes entered the analysis. The regions of interest were as follows: left anterior (F7, F5, F3, FC3, FC5), midline anterior (F1, Fz, F2, FC1, FCz, FC2), right anterior (F4, F6, F8, FC4, FC6), left central (TP7, C5, C3, CP5, CP3), midline central (C1, Cz, C2, CP1, CPz, CP2), right central (C4, C6, CP4, CP6, TP8), left posterior (P7, P5, P3, PO7, PO5, O1), midline posterior (P1, Pz, P2, PO3, POz, PO4), and right posterior (P4, P6, P8, PO6, PO8, O2). The following time windows were used for the analysis: 300-450 ms (corresponding to the LAN and the N400); 450-600 ms time window (the early P600); 600-800 ms time window (peak of the P600); and the 800-1000 ms time window (the late P600).

Finally, we performed the statistical analysis using repeated measures Analysis of Variance (ANOVA) with the within-subject factors: condition (consisting of two levels: article and adjective condition), grammaticality (two levels: grammatical and ungrammatical), hemisphere (two levels: left and right hemisphere), anteriority (three levels: anterior, central, and posterior), and their interactions. For each time window, two global repeated measures ANOVAs were performed: the first for the lateral regions (including all factors) and the second for the midline regions (excluding the factor hemisphere). The level of significance was set at $p < .05$. Additional follow-up ANOVAs were applied for interactions that were close to significance ($p < .1$). A Greenhouse and Geisser

(1959) correction was applied if the assumption of sphericity was violated, and Bonferroni corrections were used for the follow-up pairwise comparisons.

3.3 Results

3.3.1 Grammaticality Accuracy Results

Participants achieved 81.4% mean accuracy on the grammaticality judgement task (range: 66.7% – 94%; SD = 8.7%). One participant was excluded from the analysis due to an excessively low score on this task (20% correct). No further error analysis has been performed, since we did not include a grammaticality judgement question after every sentence, in order to keep the task as close to possible to the one by Popov and Basitaanse (2018).

3.3.2 ERP Results

In this section, we report only the ANOVA results that were significant or close-to-significant. The full ANOVA results, including non-significant ones, can be found in Appendix E.

Visual inspection of the waveforms indicated a positive effect starting approximately 600 ms post-stimulus onset for both conditions. The effect was present predominantly in the posterior areas and was elicited by ungrammatical sentences relative to grammatical sentences in both conditions. In line with our prediction, this positivity was not preceded by a left-lateralized negative effect in either the gender or the number condition.

In the first time window (**300-450 ms**), the global ANOVA examining lateral ROIs showed a close-to-significant three-way interaction between condition, grammaticality, and anteriority ($F(2, 44) = 3.253$, $p = .079$, $\eta^2 = .129$). However, the post-hoc tests on the three-way interaction did not yield any significant results (all *p*s > .1). The ANOVA for the midline ROIs revealed a significant three-way interaction between condition, anteriority and grammaticality ($F(2, 44) = 5.838$, $p = .018$, $\eta^2 = .210$). Once again, the follow-up *t*-tests on the three-way interaction yielded no significant effects in any of the three midline regions (all *p*s > .1).

In the second time window (**450-600 ms)**, the global ANOVA in the lateral ROIs showed a close-to-significant effect of grammaticality ($F(1, 22) = 4.196$, $p = .053$, $\eta^2 = .160$), and a close-to-significant interaction between condition, grammaticality, and anteriority ($F(2, 44) = 2.895$, $p = .097$, $\eta^2 = .116$). Follow-up analysis of the three-way interaction did not yield any significant results (all *p*s > .1). The global ANOVA for the midline ROIs produced a significant interaction between condition, anteriority and grammaticality ($F(2, 44) = 4.444$, $p = .033$, $\eta^2 = .168$) for both conditions. However, the follow-up *t*-tests for the three-way interaction showed no significant effects (all *p*s > .1).

In the subsequent time window (**600-800 ms**), the global ANOVA for the midline ROIs produced a main effect of grammaticality ($F(1, 22) = 6.039$, $p = .022$, $\eta^2 = .215$), in which ungrammatical sentences elicited more positivity than grammatical ones. There was no significant effect in the global ANOVA for the lateral regions.

In the last time window (**800-1000 ms**), the global ANOVA showed a significant interaction between grammaticality and anteriority in the lateral regions ($F(2, 44) = 11.269$, $p = .001$, $\eta^2 = .339$). In the anterior regions, the post-hoc tests showed that ungrammatical number sentences elicited a more negative response than grammatical number sentences ($t(22) = 4.73$, $p = .004$). Also, grammatical number sentences elicited a different response than grammatical gender sentences in the anterior regions (number more positive; $t(22) = -3.66$, $p = .0056$). The only other significant result in the lateral regions was that grammatical number sentences were again more positive than grammatical gender sentences ($t(22) = -2.97$, $p = .0283$). The midline analysis showed a close-to-significant main effect of grammaticality ($F(1, 22) = 3.925$, $p = .06$, $\eta^2 = .151$) and a close-to-significant three-way interaction between grammaticality, condition and anteriority ($F(2, 44) = 3.282$, $p = .074$, $\eta^2 = .130$). In the anterior region, ungrammatical number sentences were more negative than grammatical number sentences ($t(22) = 3.53$, $p = .0076$). Also, grammatical number sentences were more positive than grammatical gender sentences ($t(22) = -2.96$, $p = .028$). There were no significant results in the central region. In the posterior region, ungrammatical number sentences were more positive than grammatical number sentences ($t(22) = -4.79$, $p < .001$), and ungrammatical gender sentences were also more positive than grammatical gender sentences ($t(22) = -2.86$, $p = .0364$). Like in the anterior region, grammatical number sentences elicited a (marginally) more positive waveform than grammatical gender sentences ($t(22) = 2.72$, $p = .05$).[10]

3.3.3 Summary of ERP Results

The statistical analysis revealed that there was no left lateralized negativity (the LAN) or central negativity (the N400) in the 300-450 ms or the 450-600 ms time windows for adults with dyslexia. The first significant result was in the 600-800 ms time window, in which ungrammatical sentences in both conditions elicited

[10] The follow-up on an interaction between grammaticality and condition included four interpretable *t*-tests (grammatical vs. ungrammatical in both conditions, grammatical in condition 1 vs. grammatical in condition 2, ungrammatical in condition 1 vs. ungrammatical in condition 2). The reason for including the comparison between the grammatical levels of both conditions is to make sure that there is no difference between the two baseline levels, especially taking into account that the target nouns differ in number.

a positive effect with a midline distribution, corresponding to the P600. Since there was no interaction between grammaticality and anteriority, we can conclude that the P600 observed in this time window corresponds to an early stage of the component. The P600 effect was also present in the midline posterior region in the last time window (800-1000 ms). There was also an anterior negativity in the 800-1000 ms time window.

In Table 3.2, we summarize the ERP results from adults with dyslexia from the current study and contrast these to the adults without dyslexia reported by Popov and Bastiaanse (2018). As can be seen, there was a difference in the ERP responses to gender and number disagreement between adults with and without dyslexia in the ERP component elicitation, as well as in temporal and topographic terms

Table 3.2 Summary of ERP results for adults with dyslexia (current study) and without dyslexia (Popov & Bastiaanse, 2018) for the gender and number conditions.

	GENDER		NUMBER	
	Participants		*Participants*	
Time window	*with dyslexia*	*without dyslexia*	*with dyslexia*	*without dyslexia*
300-450 ms	x	x	x	x
450-600 ms	x	P600: all regions	x	P600: all regions
600-800 ms	P600: all regions	P600: posterior regions and right central region	P600: all regions	P600: posterior and central regions
800-1000 ms	P600: posterior regions	x	Negativity: anterior regions P600: posterior regions	P600: posterior region

Note: x = no effect detected; ms = milliseconds.

Grand mean ERP waveforms comparing brain responses of adults with dyslexia to grammatical and ungrammatical nouns in the gender condition are presented in Figure 3.1, and for the number condition in Figure 3.2.

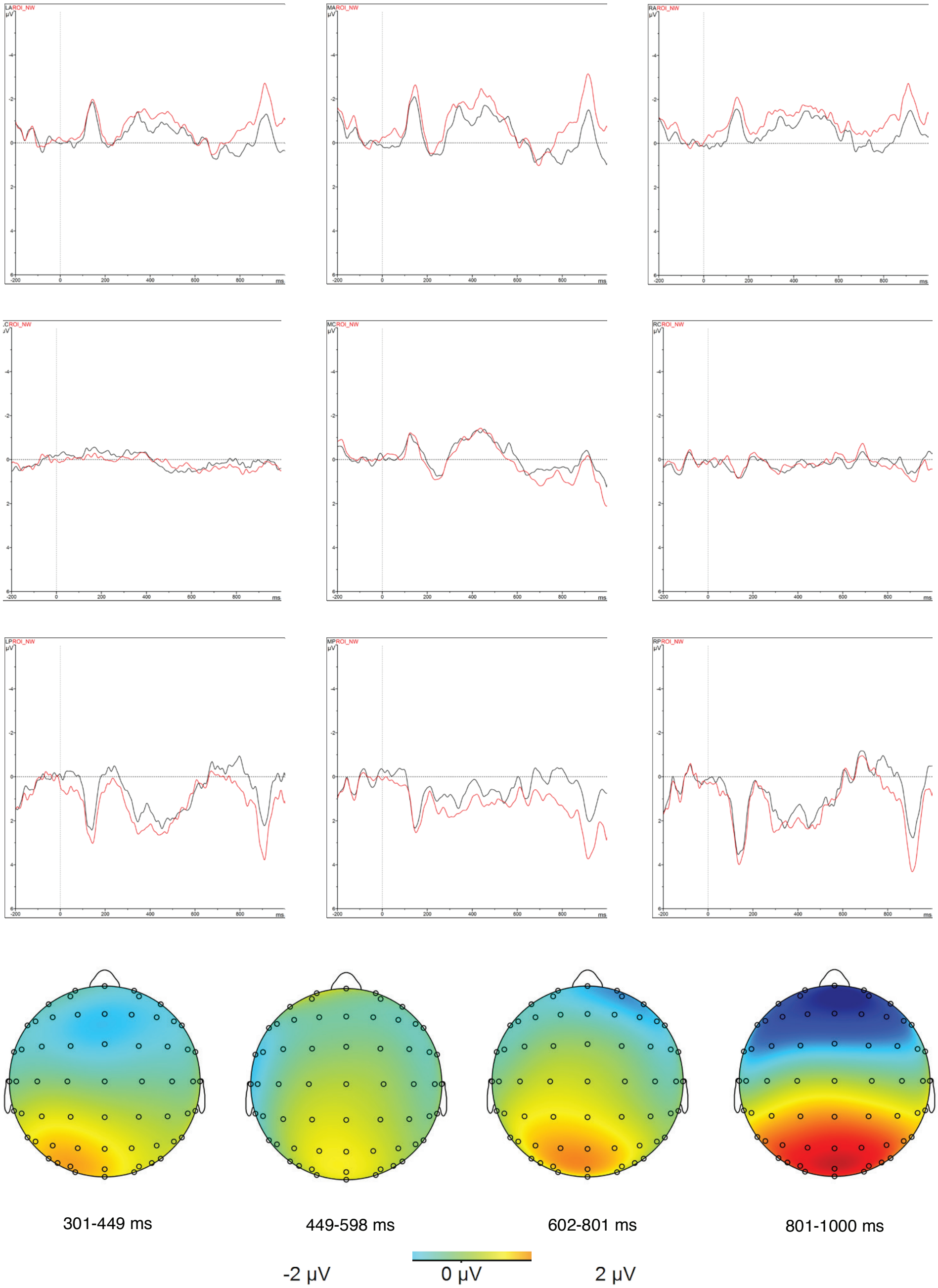


Figure 3.1 Grand average ERPs for the gender condition across all 9 ROIs: black line represents correct sentences and red line represents violated sentences. The topographic maps represent a difference between ungrammatical and grammatical sentences in the different time windows.

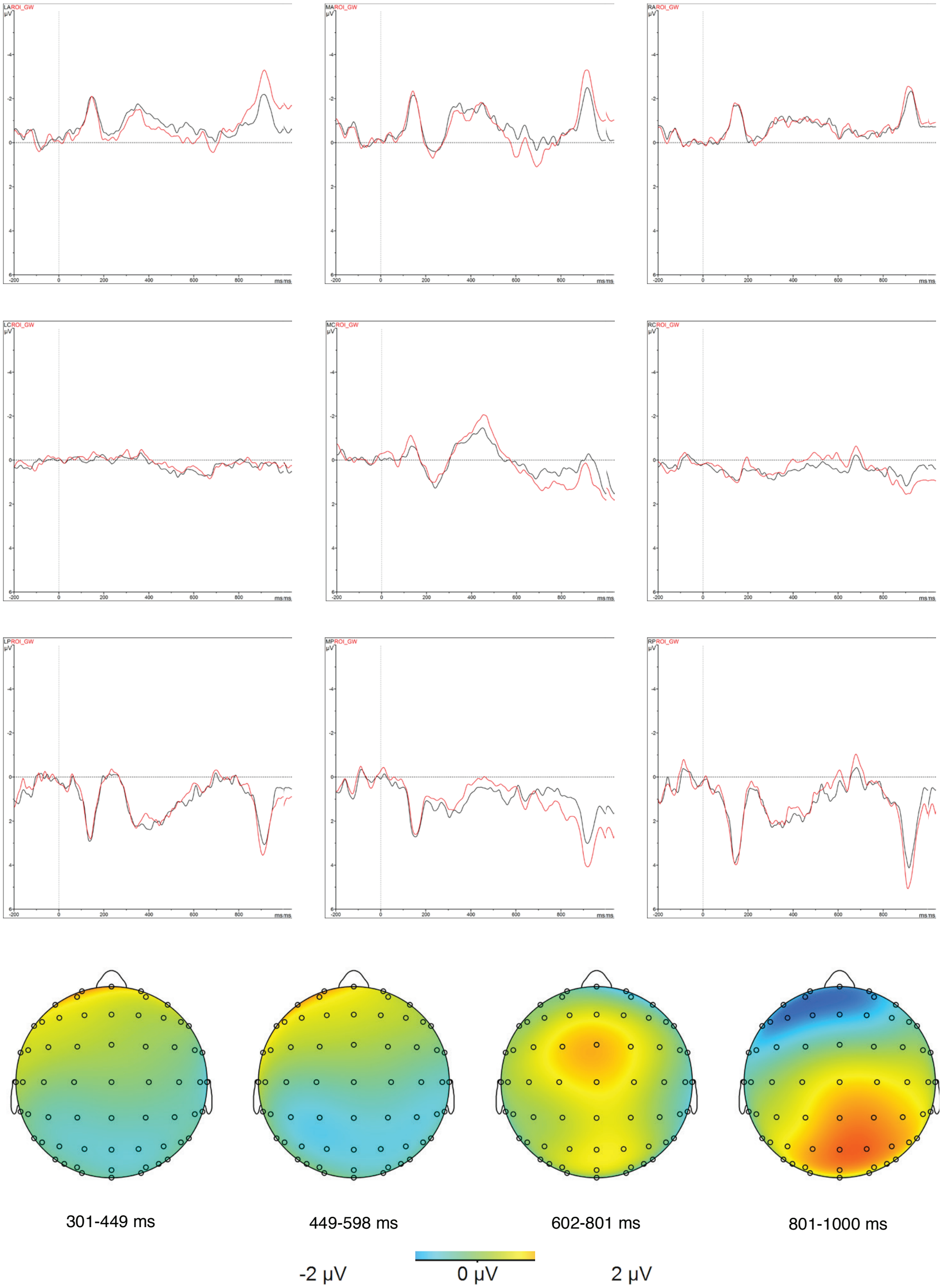


Figure 3.2 Grand average ERPs for the number condition across all 9 ROIs: black line represents correct sentences and red line represents violated sentences. The topographic maps represent a difference between ungrammatical and grammatical sentences in the different time windows.

3.3.4 Listening (Chapter 2) vs. Reading (Current Study)

Our third research question concerned the role of the presentation modality in gender and number agreement processing in dyslexia. For an easy overview, the ERP results of adults with dyslexia from Chapter 2 and the current chapter are summarized in Table 3.3. It is clear that we did see an ERP difference between listening and reading to the same stimuli. In listening, there was no effect for the gender condition, while a frontal negativity emerged in the number condition. Meanwhile, for reading, we saw a P600 for both the gender and the number condition, as well as a frontal negativity in the number condition.

Table 3.3 Summary of ERP results of adults with dyslexia in listening (Chapter 2) and reading (current chapter).

Listening		Reading	
700-900 ms	Frontal negativity: number	**450-600 ms**	x
900-1100 ms	x	**600-800 ms**	P600: all regions, gender and number
1100-1300 ms	Frontal negativity: number	**800-1000 ms**	Frontal negativity: number P600: posterior regions, gender and number

Note: ms = milliseconds; x = no effect detected. Note that the time windows are different across the different experiments due to the difference in the duration of the target noun between listening and reading.

3.4 Discussion

The current study investigated the processing of gender and number disagreement in reading in Dutch adults with dyslexia within a typical ERP violation paradigm containing grammatical and ungrammatical sentences. We compared the results of the current study with the results of the ERP study from Chapter 2, which employed the same stimuli in listening, and with the patterns shown by adults without dyslexia in Popov and Bastiaanse (2018).

3.4.1 P600 Differences between Adults with and without Dyslexia

In answer to our first research question, we did see differences in ERP patterns between adults with and without dyslexia. More specifically, qualitative, temporal and topographic differences in the ERP pattern appeared between the two groups, which is in accordance with previous ERP research on processing agreement violations in adults with dyslexia (e.g., Cantiani et al., 2013a; Rispens et al., 2006). In our study, a frontal negativity was elicited for sentences containing number disagreement, while a P600, associated with morphosyntactic repair and reanalysis (e.g., Friederici, 2002; Hagoort & Brown, 2000), emerged in response to both gender and number disagreement. The frontal negativity in our study was present in the 800-1000 ms time window, but was absent in the ERP pattern of adults without dyslexia in either condition. The P600 was elicited later for adults with dyslexia (onset at 600 ms) than the P600 found for adults without dyslexia (onset at 450 ms). The scalp distribution of the P600 was also different between the groups, with the P600 of the group without dyslexia being consistently more broadly distributed than the P600 of the dyslexia group. While the P600 for the gender condition in the adults without dyslexia was not elicited in the late P600 window, it was present in the posterior midline region for adults with dyslexia at this time window. Lastly, the P600 for both groups for the number condition was detectable in the late P600 time window, albeit with a broader distribution for the group without dyslexia.

An interesting finding of our study is that of a frontal negativity for adults with dyslexia in a late time window (i.e., 800-1000 ms) for the number condition only. This frontal negativity was puzzling, because of its late emergence and its absence in adults without dyslexia. In terms of its topographic distribution, this late frontal negativity resembles a LAN. However, the time course of this component does not coincide with the interpretation of a (delayed) LAN, given that in our study, it appeared approximately 200 ms after, and not before, the onset of the P600. Following Friederici (2002), the LAN, if elicited, should precede the P600 and reflect automatic processing of morphosyntactic violations. Therefore, in functional terms, the frontal negativity in our study is most likely not a 'true' LAN, but rather associated with processes related to late morphosyntactic integration or the recognition of the next word. The exact functional interpretation of the elicited late frontal negativity in adults with dyslexia warrants future research.

While we did find a biphasic ERP pattern in response to number disagreement in adults with dyslexia, the time course of the elicited components in our study is at odds with the results of previous studies on gender and number disagreement processing that elicited a biphasic LAN-P600 response (e.g., Barber & Carreiras, 2005, for Spanish). More specifically, in the study by Barber and Carreiras (2005), the LAN had a more typical time course in that it preceded the P600 in response to agreement mismatch. Nonetheless, our finding of a P600 for adults with dyslexia is in line with previous studies on Dutch gender and/or number disagreement that elicited the P600 (e.g., Hagoort, 2003; Hagoort & Brown, 2000; Loerts et al., 2013; Meulman et al., 2014; Popov & Bastiaanse, 2018).

These results are also in accordance with previous reports of atypical processing in dyslexia for other ERP components (e.g., Horowitz-Kraus & Breznitz, 2011). Overall, the delayed P600 effect in our study is supported by previously well-documented findings of a general slower processing speed for both visual and auditory tasks in dyslexia (e.g., Breznitz & Misra, 2003), as well as specific word recognition problems typical of dyslexia. Horowitz-Kraus and Breznitz (2011) demonstrated that adults with dyslexia possess an impaired mechanism for detecting errors while reading, which could also magnify their difficulties with morphosyntactic integration in reading found in our study. In other words, adults with dyslexia do not readily detect morphosyntactic errors while reading sentences. However, a lack of sensitivity to disagreement does not necessarily indicate an impairment in morphosyntactic processing, but rather a processing difference between the groups. This difference can partly be explained by the inherent reading difficulties in dyslexia manifested by a slower processing speed and a reduced sensitivity to grammatical violations in print.

3.4.1.1 The Structural Repair Mechanism of the P600 in Adults with Dyslexia

Regarding our second research question on the structural repair mechanism of the P600 in adults with dyslexia, we did not see differences between the elicited P600 to gender and number disagreement in adults with dyslexia. We did not make a firm prediction with regards to the structural repair mechanism in adults with dyslexia due to a lack of previous research or the P600 as a marker of structural repair and reanalysis in dyslexia. However, our results on the repair processes in dyslexia are more difficult to interpret than the mechanism underlying gender and number disagreement in adults without dyslexia. The study of Popov and Bastiaanse (2018) observed a neat asymmetry between number and gender disagreement; the longer-lasting P600 effect in the number condition reflected number disagreement being more complex to repair due to the inflectional nature of number (i.e., the existence of two structural repair options for number compared to only one structural repair option for gender).

Although a frontal negativity was present in the number condition, the P600 elicited in the dyslexia group did not differ between the two conditions, neither in temporal nor topographic terms. This may indicate that the repair process is indeed different in the two groups with participants with dyslexia being less sensitive to the repair complexity. This is in line with the idea that individuals with dyslexia process or perceive morphosyntactic agreement violations differently compared to individuals without dyslexia. Based on the later onset time of the P600, as well as its more limited scalp distribution, it seems that individuals with dyslexia perceive the violation with a delay and do not repair it as efficiently as individuals without dyslexia.

The only puzzling finding regarding the P600 is that the P600 in the gender condition was longer-lasting for participants with dyslexia compared to participants without dyslexia. This finding is reminiscent of the longer persistence of the anterior negativity in response to gender disagreement to written word-pairs in adults with dyslexia than adults without dyslexia (Rüsseler et al., 2007). In line with Rüsseler et al. (2007), we can interpret this finding as indicating a syntactic processing difficulty and longer time necessary for syntactic integration in adults with dyslexia than adults without dyslexia. Furthermore, the longer-lasting P600 effect in the gender condition in our study may be related to a general delay and later onset of the P600 (due to a general slower speed of processing, e.g., Breznitz & Misra, 2003), as well as a less efficient repair mechanism. However, it is possible that the presence of multiple factors modulated the P600 effect, which would render the comparison in terms of repair complexity with the group of adults without dyslexia uninterpretable. Therefore, our results are inconclusive regarding the structural repair processes in dyslexia.

3.4.2 ERP Responses to Agreement Violations in Reading and Listening in Adults with Dyslexia

In order to answer the final research question of this chapter, we compared the ERP effects in adults with dyslexia in response to gender and number disagreement in listening (Chapter 2) and reading (current study).

The first finding is that presentation modality does appear to be reflected in ERP responses with qualitative differences in the elicited ERP components. In listening, sentences containing number disagreement elicited a frontal negativity in adults with dyslexia, whereas no ERP effect was found for sentences containing gender disagreement. Reading sentences elicited a frontal negativity in the number condition only. Furthermore, reading sentences containing either gender or number disagreement elicited the P600, an ERP component associated with morphosyntactic reanalysis and repair, difficulties with morphosyntactic integration and increased processing load in agreement studies (e.g., Friederici, 2002; Friederici et al., 1993; Kutas & Hillyard, 1980; Molinaro et al., 2011; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995; Popov & Bastiaanse, 2018; Popov et al., 2020).

The most puzzling finding of these two studies is that of a frontal negativity, which was elicited for adults with dyslexia in response to sentences containing number disagreement in both reading and listening. As previously mentioned, this frontal negativity could only be functionally interpreted in terms of a LAN-like component, associated with an automatic detection of a morphosyntactic violation, in the early time window (i.e., 700-900 ms) in listening. In the later time windows (i.e., 1100-1300 ms for listening, and 800-1000 ms for reading), this frontal negativity was likely related to the beginning of the following word.

Finally, since qualitatively and/or temporally different ERP components were elicited for reading than for listening, it is not possible to directly compare the time course of the elicited components in the two modalities.

If we assume that listening and reading rely on the same processing mechanism, then we should expect to elicit the same ERP components in both modalities (following Friederici, 1996). Consequently, our data could be interpreted as implying that reading and listening rely on different underlying linguistic or cognitive processing mechanisms in dyslexia. Although, for adults without dyslexia, several previous studies have found no differences in the ERP pattern between reading and listening to the same stimuli (e.g., Balconi & Pozzoli, 2005; Meulman et al., 2014), others have reported different ERP patterns (e.g., Hagoort & Brown, 2000; Popov, 2017). Thus, like Popov (2017), who used the same materials in their study on Dutch adults without dyslexia, we conclude that reading and listening do not rely on the same underlying mechanism in adults with dyslexia.

An interesting finding from our two ERP studies with adults with dyslexia is that no ERP effect was elicited in response to sentences containing gender disagreement in listening, but there was a P600 in reading. In other words, adults with dyslexia were not sensitive to the presence of a subtle inflectional cue (i.e., adjectival suffix *-e*) in the gender condition in listening and required a more salient perceptual cue (e.g., the combined lexical and inflectional cues in the number condition) in order to detect the violation in listening. In contrast, they were able to detect the violation in the gender condition in reading, indicating that the gender violation in reading might be more perceptually salient than in listening. In our study, we did not directly investigate whether morphosyntactic difficulties in adults with dyslexia are caused by an underlying phonological impairment. However, it is nevertheless possible that an underlying problem in the perception, manipulation and retrieval of phonemes as the basic building blocks of language, which might in turn cause a bottleneck in working memory, is responsible for the pattern of difficulties observed across reading and listening.

Apart from corroborating the results of previous studies on difficulties with inflectional morphology in dyslexia (e.g., Altmann et al., 2008; Cantiani et al., 2013a, 2013b, 2015; Casalis et al., 2013; Joanisse et al., 2000; Rispens et al., 2004, 2006; Robertson et al., 2013), our findings have methodological implications for future studies on adults with dyslexia as an under-researched population in language research. For instance, our findings indicate that, to a different degree, both reading and listening are vulnerable in dyslexia. Thus, our results have methodological implications and emphasize the need to include reading as the presentation modality in future sentence-level studies on dyslexia. Finally, modality played a role in the ERP effects and revealed subtle differences between reading and listening to the same stimuli. Thus, the use of behavioral measures could be the reason why previous studies found no differences in the performance of children with dyslexia compared to children without dyslexia in reading and listening (Antón-Méndez et al., 2019; Casalis et al., 2013). Since Raveh and Schiff (2008) did find differences between reading in listening for adults with and without dyslexia on a morphological priming task, we assume that the use of a priming paradigm, similar to the use of ERPs, presents a more sensitive method of detecting the subtle morphosyntactic processing difficulties in individuals with dyslexia. Hence, the results of our two ERP studies highlight the necessity of using more fine-grained measures, as well as different presentation modalities, to tap into morphosyntactic differences between adults with and without dyslexia. This conclusion is also borne out by Cantiani et al. (2013a), who argues that, unlike ERPs, behavioral measures can only identify the results of cognitive processes (e.g., the number of correct/incorrect responses), rather than pinpointing the exact cognitive process involved in language processing.

3.5 Conclusion

The current study is the first to explore electrophysiological responses of adults with dyslexia when reading full sentences with morphosyntactic agreement violations and to compare them to listening to the same stimuli. In the visual modality, we found a P600 in response to both gender and number disagreement, while a frontal negativity was present for number disagreement only. Compared to adults without dyslexia, adults with dyslexia appear to be less sensitive or do not readily detect grammatical violations in reading. Our results confirm previous research regarding the lack of sensitivity to inflectional morphology in adults with dyslexia. Moreover, the results of the current study are in line with previous findings of temporal differences in the P600 elicitation and topographic differences in the P600 distribution between adults with and without dyslexia. However, our results are inconclusive regarding the nature of structural repair processes in dyslexia. Whether this is a consequence of the morphosyntactic manipulation or reading as the presentation modality placing additional demands on the parser remains a topic for future research. Regarding presentation modality, the ERP pattern for adults with dyslexia differed depending on the modality of presentation, which is a methodologically significant finding for future studies. Finally, our results confirm that ERPs constitute a sensitive method for investigating subtle morphosyntactic differences between adults with and without dyslexia.

In the previous two chapters, we investigated the processing of within-phrase disagreement in adults with dyslexia using ERPs. It remains to be seen whether adults with dyslexia process across-phrase disagreement differently than within-phrase disagreement. Another question that arises is whether another method that is sensitive to the temporal aspects of agreement violation processing (i.e., self-paced reading) can capture the subtle morphosyntactic differences between adults with and without dyslexia. These issues will be explored in the following chapter.

CHAPTER 4

The Processing of Subject-Verb (Dis)agreement by Dutch Adults with and without Dyslexia: A Self-Paced Reading Study

4.1 Introduction

As mentioned in the previous chapters, difficulties with morphosyntactic processing in individuals with dyslexia across the lifespan have been reported for both oral comprehension and written production. In particular, a number of studies with individuals with dyslexia have reported a lack of sensitivity to inflectional morphology in general (production: Altmann et al., 2008; Joanisse et al., 2000; Robertson et al., 2013; comprehension: Casalis et al., 2013) and to subject-verb agreement morphology in particular (Antón-Méndez et al., 2019; Cantiani et al., 2013a, 2013b, 2015; Rispens & Been, 2007; Rispens et al., 2004, 2006). Different causes of morphosyntactic processing weaknesses in dyslexia have been proposed, including an underlying phonological processing deficit (e.g., Rispens et al., 2004; Shankweiler et al., 1986) and working memory limitations (e.g., Robertson & Joanisse, 2010; Stella & Engelhardt, 2019; Wiseheart et al., 2009). However, other studies have also found evidence for a primary and independent morphosyntactic processing difficulty in individuals with dyslexia (e.g., Antón-Méndez et al., 2019; Cantiani et al., 2013b).

Despite an increase in the number of students entering higher education with a diagnosis of dyslexia, most likely due to improved assessment protocols (Callens et al., 2012), dyslexia in this population – and especially sentence processing in dyslexia – has largely been ignored in psycholinguistic literature (Engelhardt, 2020). In this chapter, we examine the influence of linear distance (as a measure of working memory load) on subject-verb (dis)agreement processing in Dutch adults with dyslexia using a psycholinguistic self-paced reading (SPR) experiment with behavioral measures. In line with previous research (e.g., Raveh & Schiff, 2008; Wiseheart & Altman, 2018; Wiseheart et al., 2009), we assume that focusing on the group of university students with dyslexia enables us to minimize the confound of reading as the mode of presentation, since this subgroup of high-achieving individuals with dyslexia are less prone to the influence of diminished reading experience or educational attainment.

4.1.1 The Role of Memory in Sentence Processing in Dyslexia

Previous research has demonstrated that short-term memory (STM) and working memory (WM) are two separate constructs, but that they measure similar underlying processes (Unsworth & Engle, 2007). One of the most prominent models of STM and WM is the multi-component framework by Baddeley (1986; see also: Baddeley, 2000, 2003; Baddeley & Hitch; 1974). In Baddeley's framework (Baddeley, 1986), STM is a temporary storage mechanism (measured by simple span tasks), while WM (measured by complex span tasks) is a system for processing, integration and manipulation of stored information during the performance of a range of cognitive tasks, including reading. Furthermore, Baddeley's model (Baddeley, 1986) consists of several modality-specific underlying systems: the phonological loop (phonological information processing); the visuospatial sketchpad (visual and spatial information processing); episodic buffer (temporary storage of novel information); as well as a central executive (component that oversees the other systems).

Different aspects of working memory, including the phonological loop and the central executive, have been found to be impaired in both children and adults with dyslexia (e.g., Cohen-Mimran & Sapir, 2007; Gathercole et al., 2006; Kibby et al., 2004; Smith-Spark & Fisk, 2007; Smith-Spark et al., 2003, 2016; Swanson et al., 1996). Furthermore, several studies have linked both STM and WM constraints to morphosyntactic processing problems in individuals with dyslexia in studies involving production (e.g., Shankweiler & Crain, 1986; Wiseheart & Altmann, 2018) and comprehension of spoken (e.g., Rispens & Been, 2007; Robertson & Joanisse, 2010; Shankweiler & Crain, 1986), and written language (e.g., Jiménez et al., 2004; Stella & Engelhardt, 2019; Wiseheart et al., 2009). However, both Wiseheart et al. (2009) and Robertson and Joanisse (2010) found that group differences between individuals with and without dyslexia disappeared when scores on tests for WM and word reading were statistically controlled. This finding is consistent with the *phonological processing limitation hypothesis* by Shankweiler et al. (1982), which explains syntactic processing difficulties observed in dyslexia in light of the underlying phonological deficit (e.g., Ramus et al., 2003; Snowling, 2000). According to this hypothesis, difficulties with the phonological, low-level, building blocks of language tax working memory, which in turn impedes higher-level linguistic mechanisms, such as the processing of morphosyntax. Thus, under this account, WM constraints, rather than morphosyntactic processing difficulties, cause problems in syntactic processing (e.g., Shankweiler & Crain, 1986; Shankweiler et al., 1982). However, Delage and Durrleman (2018) investigated the production of syntactically complex structures in French-speaking children with dyslexia and found that (morpho) syntactic processing difficulties in dyslexia were caused by syntactic complexity, rather than memory constraints. Thus, their results contradict previous findings of a link between WM and sentence processing in dyslexia.

4.1.2 The Influence of Linear Distance and Working Memory on Sentence Processing

WM has been argued to play a central role in sentence processing, and in particular in the processing of syntactically complex sentences (e.g., Just & Carpenter, 1991; King & Just, 1991; Nicenboim et al., 2015; but see, e.g.: Caplan &

Waters, 1999; Martin, 1993; Waters & Caplan, 1996, 2004). A number of theories have been proposed that account for the processing of an increase in memory load (i.e., increase in the number of words: linear distance, or sentence complexity) in sentences, including memory-based and structure-based theories of sentence processing (see Levy et al., 2013; Nicenboim et al., 2015, for an overview). Among the memory-based accounts of sentence processing, the theory that best explains the processing of (linear) distance in sentences is Gibson's (1998, 2000) Dependency Locality Theory (DLT). DLT posits that sentence processing depends on two main metrics: storage costs (i.e., maintaining the dependency between the constituents in memory) and integration costs (i.e., integrating a new word into the existing dependency). In general, memory-based accounts of sentence processing characterize distance as linear distance: the number of words in a linear order intervening between the elements in an agreement relationship, especially the number of new discourse referents (Gibson, 1998, 2000). Under this account, difficulty in sentence parsing is attributed to the integration cost caused by increasing the linear distance between a constituent held in memory and the dependent to which it attaches (Gibson, 1998, 2000). Previous research has characterized linear distance as a measure of WM load (e.g., Baumann, 2014). In case of a longer linear distance, more WM demands are placed on the parser. As a result, longer-distance dependencies are more difficult to process than shorter-distance dependencies. Thus, DLT posits that the introduction of intervening constituents between the subject and the verb will influence subject-verb agreement processing by requiring additional WM resources for sentence parsing.

Previous research has quantified the processing difficulty induced by increasing the distance between a head and its dependent by using different methods. For instance, SPR experiments show that a longer dependency between the dependent element and its head causes *locality effects*: longer reading times (RTs) at the integration point, where the dependency is resolved and the stored element can be integrated in sentence structure (e.g., Bartek et al., 2011; Gibson, 2000; Grodner & Gibson, 2005; Grodner et al., 2002; Liu & Wang, 2019; Warren & Gibson, 2002). In event-related potential (ERP) studies, processing effort caused by integrating a longer dependency length is reflected in the increase of the elicited ERP component amplitude (e.g., Alatorre-Cruz et al., 2018; Fiebach et al., 2002; Hammer et al., 2008; Kluender & Kutas, 1993; Rispens & de Amesti, 2017; Vos et al., 2001; but see: Kaan, 2002; Phillips et al., 2005). Finally, the processing effort caused by the increase in dependency length is also reflected in lower response accuracy on a grammaticality judgement task (e.g., Kaan, 2002; Rispens & de Amesti, 2017; but see: Vos et al., 2001).

However, other SPR studies found evidence for anti-locality effects: a reduction in RTs at the integration site, where the dependency is completed, with increased distance between the dependent elements (e.g., Levy & Keller, 2013; Nicenboim et al., 2015; Vasishth, 2003; Vasishth & Lewis, 2006). Nicenboim et al. (2015) found evidence for both locality and anti-locality effects in their SPR and eye tracking research on Spanish. Anti-locality effects in this study were explained by an expectation-based theory of sentence processing (Levy, 2008). Under this account, in a subject-verb dependency, individuals expect the verb to appear and complete the dependency, but do not know when it will appear. Once the verb does show up, there is low surprisal, leading to faster processing speed (e.g., longer RTs). Nicenboim et al. (2015) suggested that individual WM capacity influences dependency resolution, such that locality effects may transform into anti-locality effects in participants with a larger WM capacity. More specifically, they argued that when processing material with a high WM demand, the parser uses a strategy of engaging in faster reading in order to release the memory load (similar to the SPR results by Van Dyke & McElree, 2006).

A recent SPR study by Liu and Wang (2019) compared the effects of linear distance (i.e., the number of words between constituents in a long-distance dependency in a linear order) to those of structural distance (intervening syntactic nodes) on sentence processing by younger and older adults in Mandarin Chinese. They found that an increase in linear distance was associated with lower accuracy, whereas an increase in structural distance was associated with longer RTs. Older adults were more influenced by linear distance and showed a poorer performance on an offline sentence comprehension task compared to younger adults which was attributed to an age-related decrease in WM.

4.1.3 Current Study

The current study is the first to use SPR to investigate the influence of linear distance on the accuracy and RTs in sentences containing subject-verb (dis) agreement in Dutch adults with and without dyslexia. The advantage of SPR is that it is an inexpensive and convenient method, which offers fine-grained information on participants' processing across time, since it requires the reader to consider each word in a sentence. Unlike in ERP experiments, participants can read at their own pace rather than at a pace pre-determined by the experimenter. Thus, SPR offers higher ecological validity compared to ERPs. However, in a non-cumulative SPR word-by-word presentation, unlike natural reading and eye tracking paradigms, participants are not able to re-read words. This has the advantage of enabling us to manipulate the extent to which the participants' WM is taxed on our task, as participants need to store all the words of a sentence in memory, in order to perform the grammaticality judgement task.

For the current experiment, we developed an SPR study using subject-verb (dis)agreement processing with agreement violations at the verb, which was either in a short- or a long-distance from the subject. The linear distance (i.e., the number of intervening words between the subject and the verb) was used as a measure that reflected the WM load of the task. In the current study, we were interested in both the behavioral (accuracy on the grammaticality judgement task) and the online performance (Reading Times in the critical regions) of adults with dyslexia, and the Reading Times of typical readers.

4.1.3.1 Research Questions and Predictions

We formulated the following research questions and predictions for our investigation of the effect of linear distance in sentences containing subject-verb (dis)agreement in adults with and without dyslexia:

Behavioral Grammaticality Judgement Task

> **Research Question 1:** Is there a difference in the accuracy of grammaticality judgements between participants with and without dyslexia?

Prediction 1: Overall, we predict participants with dyslexia will have a lower accuracy than participants without dyslexia on the grammaticality judgement task (e.g., Cantiani et al., 2013a; Miller-Shaul, 2005; Rüsseler et al., 2007; our experiments from chapters 2 and 3; but see: Rispens et al., 2006).

> **Research Question 2:** In the group of adults with dyslexia, our group of interest, is there a difference in accuracy across the different distance and grammaticality conditions?

Prediction 2: Since WM problems are pervasive in dyslexia (e.g., Smith-Spark & Fisk, 2007), we expect that an increase in linear distance (i.e., WM load) will affect adults with dyslexia (following the DLT, Gibson, 1998, 2000). Thus, we expect adults with dyslexia to have lower accuracy on sentences with a long distance between the subject and the verb compared to those with a short distance. Additionally, adults with dyslexia have been found to show a lack of sensitivity to inflectional morphology (e.g., Rispens et al., 2006). Thus, we predict that adults with dyslexia will not notice ungrammatical verb forms and will thus have a worse performance in judging the accuracy of ungrammatical than grammatical sentences on the grammaticality judgement task (in line with Cantiani et al., 2013a).

Reading Times

> **Research Question 3:** For adults with and without dyslexia, do distance and grammaticality affect the Reading Times (RTs) for the three regions of interest (i.e., verb, spill-over and final word)?

Prediction 3: We predict that adults with dyslexia will show longer RTs for the three regions of interest in sentences in the long than in the short condition, given their WM difficulties (e.g., Smith-Spark & Fisk, 2007). Additionally, we predict that adults with dyslexia will not show a difference in RTs of the three regions of interest in grammatical and ungrammatical sentences. In line with DLT (Gibson, 1998, 2000), we expect adults without dyslexia to have a lower accuracy for sentences with long than short linear distance. Similarly, we predict that adults without dyslexia will have longer RTs for the three regions of interest in ungrammatical than grammatical sentences, in line with DLT (Gibson, 1998, 2000).

4.2 Method

4.2.1 Participants

A total of 97 participants were initially recruited for the study (28 male, mean age = 23.23 years, *SD* = 3.24, range: 18-32). Thirty participants initially belonged to the group with dyslexia and 67 participants to the group without dyslexia. Since some participants were excluded from the study (see the descriptions of participant groups below for more details), the final group of participants consisted of 85 participants (24 male; mean age = 23.14 years, *SD* = 3.17, range: 18-30; 26 participants with dyslexia; 59 participants without dyslexia). There was no significant difference in age between either the initial ($t(95) = -0.15$, $p = .881$) or final groups of participants with and without dyslexia ($t(84) = 0.63$, $p = .531$).

The inclusion and exclusion criteria for all participants in the study were as follows: they should be native speakers of Dutch, with no (history of) neurological or psychiatric disorders (e.g., epilepsy, ADHD, or Autism Spectrum Disorders), normal or corrected-to-normal vision and no hearing impairments.

Prior to the experiment, all participants received written information about the study and gave informed consent online. Participants received financial compensation of 8 EUR per hour in return for their participation. The experiment was approved by the local ethics committee (Research Ethics Committee (CETO), Faculty of Arts, University of Groningen).

4.2.1.1 Participants with Dyslexia

All participants with dyslexia were required to have a clinical diagnosis of dyslexia and a formal and valid dyslexia statement prior to taking part in the experiment. Another inclusion criterion was the absence of another language impairment apart from dyslexia, and no history of speech therapy, as confirmed by the intake questionnaire. We adhered to the diagnostic criteria of the Dutch Dyslexia Foundation (SDN et al., 2016) and individuals with dyslexia were required to have either a clinical (< *Pc* 10) or a subclinical score (< *Pc* 16) on tests related to single word reading, pseudo-word reading and word spelling.

Of the 30 participants with dyslexia recruited for the study, one participant was excluded due to no longer being characterized as having a clinical dyslexia diagnosis based on the diagnostic tests. Three additional participants were excluded due to not completing the SPR task, leaving 26 participants with dyslexia (8 male; mean age: 22.69, *SD* = 2.59, age range: 18-27).

4.2.1.2 Participants without Dyslexia

In addition to the above-mentioned exclusion and inclusion criteria, all participants without dyslexia declared no history of developmental language disorders (including dyslexia), speech disorders, and reading or spelling difficulties. Of the 67 participants without dyslexia who were recruited, eight participants without dyslexia were excluded from the analysis due to a clinical (< *Pc* 10) or subclinical score (< *Pc* 16) on one (seven participants) or more (one participant) of the three dyslexia diagnostic tests (i.e., word reading, pseudo-word reading or word spelling). The sample of participants without dyslexia ultimately consisted of 59 participants (16 male; mean age: 22.57, *SD* = 3.4, age range: 18-30).

4.2.2 Behavioral Measures

At the beginning of the study, a set of behavioral measures was administered to participants with dyslexia in order to confirm the dyslexia diagnosis, since we could not control for how the participants' dyslexia was originally diagnosed. The tests were selected based on the short protocol for dyslexia assessment (Tops et al., 2012). Tops et al. (2012) found support for the reliability and validity of a select number of tests for diagnosing dyslexia from a comprehensive assessment battery for dyslexia diagnosis in Dutch (Test voor Gevorderd Lezen en SCHrijven – GL&SCHR; De Pessemier & Andries, 2009). Participants with dyslexia included in the study displayed either a clinical (< *Pc* 10) or subclinical (< *Pc* 16) score on word reading fluency (One Minute Test, or 'Eén-minuut-test'; Tops et al., 2019), pseudo-word reading fluency (De Klepel; Van den Bos et al., 1994), and/or spelling to dictation (the spelling subtest of the GL&SCHR), thus confirming the dyslexia diagnosis. Additional tests tapping into phonological awareness (Spoonerisms, and Omkeren, or 'Reversals', GL&SCHR), and morphology and syntax knowledge (morphology and syntax subtest of the GL&SCHR) were administered. The test battery also included a Dutch vocabulary test (Vander Beken et al., 2018). Finally, we administered several digit span tasks (WAIS-IV-NL; Wechsler IV, 2012), and a shortened non-word repetition task (S-NWRT; Le Clercq et al., 2017). These tests are described in Appendix A.

The scores of both groups of participants on the behavioral measures are shown in Table 4.1. As can be seen, there were group differences on all tests, and participants with dyslexia performed worse on all the behavioral measures than participants without dyslexia.

Table 4.1 Scores of participants with and without dyslexia on the behavioral measures.

	Participants with dyslexia (n = 26)		**Participants without dyslexia (n = 59)**			
	***M Pc* score**	***SD***	***M Pc* score**	***SD***	***t***	***p***
Dyslexia diagnostic tests						
Word reading fluency	5.27	7.34	70.26	19.38	17.03	< .001
Pseudo-word reading fluency	5.59	9.18	67.42	22.63	13.70	< .001
Spelling to dictation – raw score	14	20.38	62.71	21.94	8.31	< .001
Other language tests						
Spoonerisms	29.64	29.76	83.71	24.31	7.02	< .001
Reversals	23	23.86	80.16	33.69	7.23	< .001
	M	***SD***	***M***	***SD***	***t***	***p***
Morphology & syntax – raw score	57.55	24.22	70.90	24.40	2.25	.028
Vocabulary	41.05	7.84	51.61	9.51	4.28	< .001
Non-word repetition	13.23	4.76	16.1	4.13	2.56	.012
	M	***SD***	***M***	***SD***	***t***	***p***
Memory tests						
Digit span forwards	9.27	1.98	11.55	2.39	3.78	< .001
Digit span backwards	8.27	1.67	10	2.55	3.14	.002
Digit span sequencing	8.1	1.73	9.63	2.35	2.95	.004
Letters & numbers sequencing	18.64	1.84	20.68	2.24	3.63	< .001

Note: M = mean; Pc = percentile; SD = standard deviation; t = t-value; p = p-value.

4.2.3 Acceptability Ratings for the Materials

Prior to the experiment, an acceptability ratings survey was created in order to confirm the (un)grammaticality of the materials. All potential experimental sentences, both grammatical and ungrammatical, were included in the survey. Participants were asked (in Dutch): “Is this sentence grammatically correct?”

The possible answers were either 'yes' or 'no'. Participants were asked to answer every question in the survey. There were 384 sentences divided over three surveys, with 128 sentences in each survey.[11] Each participant completed only one survey. The survey was carried out via an online survey platform (www.SurveyMonkey.com). A total of 36 Dutch native speakers without dyslexia (10 male; mean age: 38, age range: 20-85, *SD* = 16.64) who did not participate in the main experiment completed the survey. A sentence had to be correctly judged as either grammatical or ungrammatical by at least 80% of the participants in order to be included in the experimental items. Of the 384 sentences, 15 did not fulfill the 80% criterion. These sentences were then either excluded or adjusted and unanimously approved by additional 7 Dutch native speakers who did not complete the original survey.

4.2.4 Materials and Design

The experiment consisted of a 2 × 2 design, with variables Distance (short vs. long) and Grammaticality (grammatical vs. ungrammatical).

The final materials consisted of 192 experimental sentences and 64 fillers. The sentences were divided into 4 lists, each containing 80 sentences (48 experimental sentences and 32 fillers, both grammatical and ungrammatical). The materials for the final version of the experiment were constructed with the use of 19 unique Dutch verbs. All verbs had lemmas of 5-6 letters and two syllables in length, and were of high frequency (mean lemma frequency: 4014, mean logarithmic word frequency – log10WF: 3.17; SUBTLEX-NL word frequency database for Dutch; Keuleers et al., 2010), transitive and did not have an infinitive form that could be homophonous to a noun (e.g., *boeken*$_{Noun/Verb}$ 'books/to book'). Full materials can be found in Appendix C.

For the experimental items, each verb was used to construct at least four sentences: one short distance grammatical sentence, one short distance ungrammatical sentence, one long distance grammatical sentence, and one long distance ungrammatical sentence. All 48 stimuli were divided over four lists (24 sentences per short/long condition per list, half grammatical and half ungrammatical). Each participant was exposed to only one list. If a grammatical sentence was in one list, the ungrammatical version of the same sentence was in another list. Likewise, if a short sentence was in one list, its long counterpart was in another list. Thus, each participant saw each verb only once, either in a grammatical or in an ungrammatical sentence, which contained either a short or a long linear distance. Examples 1-4 illustrate the sentences used in the experiment:

[11] The experiment described here was intended to be carried out as an ERP (event-related potentials) experiment. Hence, a large number of sentences suitable for an ERP experiment was created. However, due to the outbreak of the COVID-19 pandemic, the experiment was adapted into a SPR one, with a lower number of sentences. The sentences with the highest acceptability ratings (>85% accurately judged sentences) were included in the SPR study.

(1) *Short grammatical*

De	jongen	is	goed	bezig,	omdat	hij
nieuwe	groepen	leidt	met	de	begeleider.	
the	young man$_{3.P.SG.M(asculine)}$	is	doing	well,	because	he$_{3.P.SG.M}$
new	groups	leads$_{3.P.SG}$	with	the	supervisor	

‘The young man is doing well, because he leads new groups with the supervisor.’

(2) *Short ungrammatical*

De	jongen	is	goed	bezig,	omdat	hij
nieuwe	groepen	*leiden	met	de	begeleider.	
the	young man$_{3.P.SG.M}$	is	doing	well,	because	he$_{3.P.SG.M}$
new	groups	*lead$_{PL}$	with	the	supervisor	

(3) *Long grammatical*

De	jongen	is	goed	bezig,	omdat
hij	voor	het	bedrijf	de	grote
nieuwe	groepen	leidt	met	de	begeleider.
the	young man$_{3.P.SG.M}$	is	doing	well,	because
he$_{3.P.SG.M}$	for	the	company	the	large
new	groups	leads$_{3.P.SG}$	with	the	supervisor

‘The young man is doing well, because he leads large new groups for the company with the supervisor.’

(4) *Long ungrammatical*

De	jongen	is	goed	bezig,	omdat
hij	voor	het	bedrijf	de	grote
nieuwe	groepen	*leiden	met	de	begeleider.
the	young man$_{3.P.SG.M}$	is	doing	well,	because
he$_{3.P.SG.M}$	for	the	company	the	large
new	groups	*leiden$_{PL}$	with	the	supervisor

All experimental sentences contained subject-verb (dis)agreement. The agreement mismatch for the experimental items was created by a mismatch between the subject and the verb in the embedded clause, which created a violation that the parser would recognize only once it reaches the clause-final verb (see examples 1 and 2). The short and the long sentences had the same basic structure, consisting of a main clause and an embedded *omdat*-clause ('because'-clause; see examples 1-4). The main clause always started with a singular or plural subject NP (e.g., *de man/de mannen* 'the man/the men'), and a copula. The embedded clause always began with the word *omdat* ('because'), followed by a personal pronoun (e.g., *hij/ ze* 'he/they'). An NP preceded the verb in both conditions. The linear distance (as measured by the number of words) between the personal pronoun and the target verb in the *omdat*-clause was kept constant in each condition. Thus, in the short condition, the linear distance between the personal pronoun and the target verb in the *omdat*-clause comprised seven words (or two constituents: PP and NP), while the linear distance in the long condition comprised two words (one constituent, an NP). The subject NP (noun phrase) of the main clause was singular in 50% of the sentences and plural in 50% of the sentences. The pronoun in the embedded clause was correspondingly singular (*hij* = 'he') in 50% of the embedded clauses and plural (*ze* = 'they') in 50% of the embedded clauses.[12]

The filler sentences were the filler sentences used in an experiment by Dragoy et al. (2011). The fillers consisted of 32 grammatical sentences and their 32 ungrammatical counterparts. In both the experimental and the filler conditions, the embedded clause always ended with a singular or plural target verb, followed by a three-word prepositional phrase (PP). The purpose of the final PP was to ensure that any potential sentence 'wrap-up' effects associated with processing the end of the sentence would not obscure the effect of the RTs on the verb (following King & Just, 1991).

4.2.5 Procedure

Prior to taking part in the experiment, all participants were sent written information about the experiment via e-mail and were asked to fill out an online consent form. They were then asked to fill out a background questionnaire and to

[12] In Dutch, 'ze' is both the third person singular feminine form and the third person plural form. Thus, the ungrammatical sentences in our stimuli with 'ze' can be construed as grammatical, but this would be pragmatically odd and syntactically less likely. Since the antecedent of the 'ze' pronoun is plural, as well as the verb that agrees with the antecedent, the number feature of the 'ze' pronoun is set as plural. Once the verb in singular is encountered, an agreement mismatch is created. Most importantly, in the acceptability ratings of the materials, participants without dyslexia who did not take part in the SPR study rated the grammatical and ungrammatical sentences with 'ze' correctly.

perform a number cognitive and dyslexia diagnostic tests administered via Qualtrics (www.qualtrics.com), and to take part in a behavioral testing session via Google Meet or Skype. After completion of the behavioral testing battery, participants were sent a link to the SPR experiment on the Ibex Farm platform (https://spellout.net/ibexfarm/). Oral instructions about the experiment were provided during the Google Meet or Skype testing session, while written instructions about the experiment were provided both in the email and the Ibex Farm experiment. For the SPR experiment, participants were instructed that they had to sit in a quiet room with no distractions, to have a good internet connection, to complete the experiment in one session on a desktop computer or laptop (not mobile phone), to take as few breaks as possible and not to perform other activities during the experiment.

Participants were told that they were taking part in a so-called ‘self-paced reading’ experiment, in which sentences presented word-by-word. Participants could determine their own reading speed, since they had to press the space button on their keyboard in order to proceed further and for a new word to be displayed. The experiment used a non-cumulative presentation, in which only one word at a time was displayed on the screen, rather than the entire sentence. Therefore, participants had to keep the sentence in their memory in order to judge the grammaticality of each sentence. Participants were asked to rate whether a sentence was grammatically correct or not by pressing either the button ‘p’ or ‘q’ on their keyboard, or clicking on the word ‘Yes’ or ‘No’ on the screen. The assignment of the buttons was counterbalanced in the experiment. The experiment began with 5 practice sentences, followed by a total of 80 sentences used in the experiment (48 experimental sentences and 32 fillers).

4.2.6 Data Collection and Pre-processing

Accuracy on the grammaticality judgement task was calculated automatically, and RTs for the three critical regions were automatically recorded in milliseconds (ms) by IbexFarm (Drummond, 2013). Both correctly and incorrectly judged sentences were included in the analysis. Pre-processing and statistical analyses were conducted on the raw data with the use of the R statistical software (R Core Team, 2020).

4.2.6.1 Pre-Processing

The practice items and the filler sentences were not included in the analysis. All RTs below 200 ms and above 10,000 ms were regarded as outliers and were removed from the analysis. The lower threshold of 200 ms was chosen, since it is not possible to read a word faster than 200 ms, and such a short RT in SPR studies typically indicates an accidental button press (e.g., Jegerski, 2014). We chose an upper threshold of 10,000 ms to account for longer RTs of participants with dyslexia, which are well documented (e.g., Shaywitz & Shaywitz, 2005). Since the experiment was not supervised, reading a word for longer than 10,000 ms likely indicated that a participant was engaged in an activity other than just reading. Our trimming procedure resulted in the exclusion of 8.35% of the RT data.

For the analysis, we used two factors, divided into two levels: distance (short and long) and grammaticality (grammatical and ungrammatical). Subsequently, three regions of interest were created, based on the position of the grammatical violation in the sentence. The three regions for which RTs were measured were as follows: Region 1 – Verb (the target region, consisting of the grammatical or ungrammatical verb and the point at which the grammatical violation could be detected); Region 2 – Spill-over (the two words immediately following the verb, i.e., the preposition and the article in the PP); and Region 3 – Final word (of the sentence; the head noun of the PP). We also measured the RTs for the word directly preceding the target verb (i.e., the baseline). The materials were created in such a manner that the critical regions only differed in the grammaticality of the verb, regardless of linear distance and grammaticality. The distribution of the excluded data by regions of interest is as follows: Baseline: 0.54%; Region 1 – Verb: 1.05%; Region 2 – Spill-over: 2.31%; and Region 3 – Final word: 3.45%.

4.2.7 Data Analysis

The analysis was conducted with the use of the *glmer* and *lme4* packages (Bates et al., 2015) in the R statistical software environment (R Core Team, 2020). Accuracy data were automatically logit-transformed in the (generalized) linear mixed-effects regression (GLMR) model. A Welch two sample t-test was used to compare the accuracy data of participants with and without dyslexia on the grammaticality judgement task. Region length was included in the model as a covariate, so that the results would not be influenced by differences in the number of letters between the regions. In order to answer the second research question on the performance of adults with dyslexia on the grammaticality judgement task, a separate 2x2 GLMR model with the factors distance and grammaticality was fit exclusively for adults with dyslexia.

Finally, in order to answer the third research question on the RTs of adults with and without dyslexia in the regions of interest, we fit separate GLMR models per region and per participant group, with the factors distance (short vs. long) and grammaticality (grammatical vs. ungrammatical).[13] Individual

[13] Following the research questions, the reason why we conducted separate analyses for the two participant groups is that adults with dyslexia read overall slower than adults without dyslexia (e.g., Breznitz & Misra, 2003). Thus, adults with dyslexia exhibit longer RTs than adults without dyslexia at the baseline, rendering the results of a direct group comparison uninterpretable.

participants and items were included as random intercepts (see Baayen et al., 2008). Contrast coding (sum coding) was used for experimental fixed-effects and their interaction(s).

4.3 Results

4.3.1 Grammaticality Accuracy Results

The first research question asked whether there was a difference between participants with and without dyslexia in overall accuracy on the grammaticality judgement task.

Mean accuracy on the grammaticality judgement task was 91.5% (range: 79% – 100%, *SD* = 5.7%) for participants with dyslexia, while it was 94% (range: 75% – 100%, *SD* = 4.8%) for participants without dyslexia. Overall, there was a difference in accuracy between the two groups ($t(84) = -2.68$; $p = .0075$). The mean accuracy per group per condition is displayed in Table 4.2. In sum, on the grammaticality judgement task, both groups of participants displayed close to-ceiling performance, but participants with dyslexia still performed significantly worse than participants without dyslexia.

Table 4.2 The mean percentages of correct answers on the grammaticality judgement task per group per condition.

Group	Condition	% correct answers (*SD*)
Adults with dyslexia	Short-grammatical	91.7 (2.77)
	Short-ungrammatical	93.7 (2.42)
	Long-grammatical	88.5 (3.19)
	Long-ungrammatical	92 (2.72)
Adults without dyslexia	Short-grammatical	92.5 (2.63)
	Short-ungrammatical	97.4 (1.6)
	Long-grammatical	88.6 (3.18)
	Long-ungrammatical	97.5 (1.56)

Note: SD = standard deviation.

The second research question was whether adults with dyslexia showed a difference in judging sentences with a short and long distance between the subject and the verb, as well as grammatical and ungrammatical sentences on the grammaticality judgement task. The model fit exclusively for adults with dyslexia showed no significant effects for Distance or Grammaticality, nor a significant interaction between Grammaticality and Distance (see Table 4.3).

Table 4.3 Fixed-effects results of the grammaticality accuracy data of adults with dyslexia, rounded to two decimal points.

	Estimate (*SE*)	*z*-value	*p*-value
(Intercept)	2.58 (0.26)	9.98	< .001
Grammaticality	0.32 (0.32)	1.00	.32
Distance	-0.37 (0.28)	-1.32	.19
Grammaticality × Distance	0.09 (0.43)	0.22	.83

Note: SE = standard error.

4.3.2 Reading Times

The third research question was whether distance and grammaticality affected the RTs of the three regions of interest (i.e., verb, spill-over and final word) for adults with dyslexia and adults without dyslexia. The region preceding the verb (i.e., the baseline) was also included in the analysis in order to ascertain that the differences in RTs in each group were due to our experimental manipulation. The results of the statistical analyses are reported below per region and per group. Mean RTs (in milliseconds) per region and condition for both groups of participants are provided in Table 4.4.

Table 4.4 Mean reading times (in milliseconds) of the different conditions per region of interest for participants with and without dyslexia.

Condition	**Baseline**		**Region 1 Verb**		**Region 2 Spill-over**		**Region 3 Final word**	
	Mean RT (SD)		Mean RT (SD)		Mean RT (SD)		Mean RT (SD)	
	DYS	***NDYS***	***DYS***	***NDYS***	***DYS***	***NDYS***	***DYS***	***NDYS***
Short gram.	554.19 (457.94)	440.91 (153.54)	564.68 (292.5)	486.11 (327.3)	508.75 (268.5)	447.08 (222.2)	931.64 (908.2)	900.43 (967.23)
Short ungram.	519.55 (191.2)	456.81 (287.6)	684.62 (425.2)	524.6 (331.9)	498.34 (262.4)	418.44 (209.53)	683.78 (585.58)	589.25 (631.37)
Long gram.	534.2 (233.04)	434.16 (201.66)	609.1 (365.9)	458.85 (246.4)	538.16 (337.9)	422.71 (153.8)	1041.78 (1275.6)	876.23 (951.13)
Long ungram.	554.83 (273.2)	436.08 (207.44)	741.7 (491)	491.06 (257)	539.57 (364.3)	407.16 (155.2)	883.53 (977.6)	579.92 (611.62)

Note: Mean RT = mean reading time in milliseconds, rounded to two decimal points; RT = reading time; *SD* = standard deviation; DYS = participants with dyslexia; NDYS = participants without dyslexia; Short gram. = short-distance grammatical condition; Short ungram. = Short-distance ungrammatical condition; Long gram. = Long-distance grammatical condition; Long ungram. = Long-distance ungrammatical condition.

The mean RTs of adults with and without dyslexia per region and per condition are displayed below in Figures 4.1a+b., while the mean RTs of adults with and without dyslexia for the factors Distance and Grammaticality are displayed in Figures 4.2a+b.

Figure 4.1a.

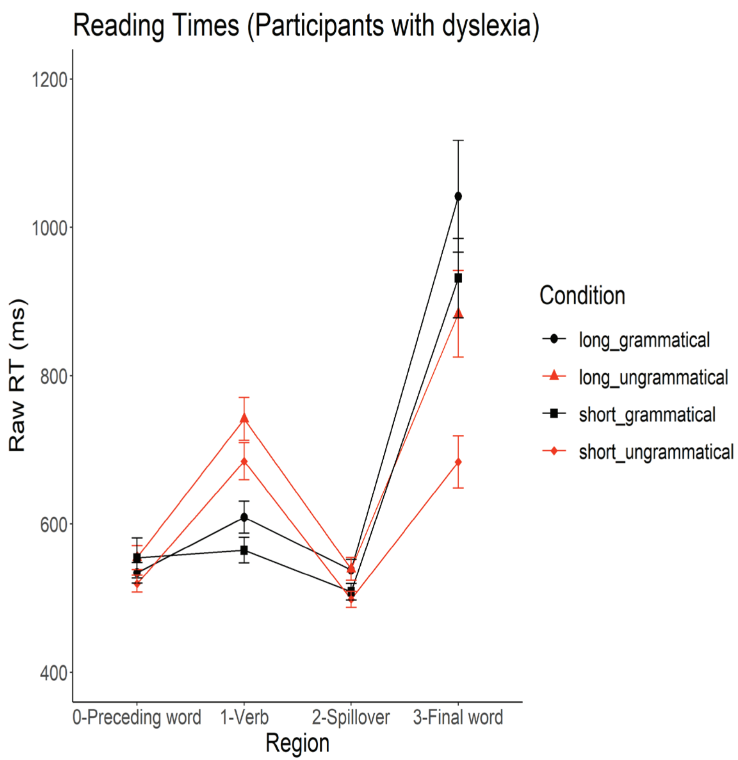
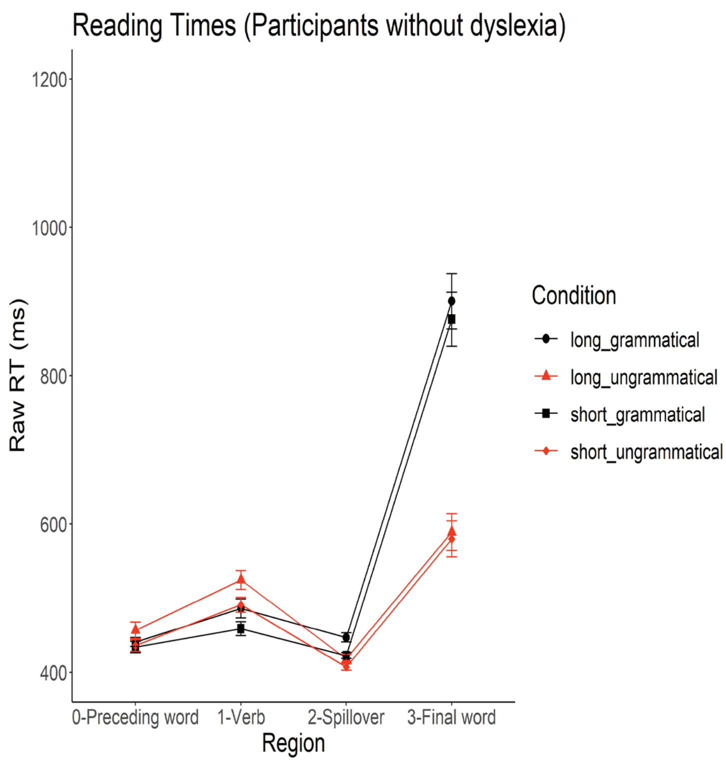


Figure 4.1b.



Note: RawRT = raw reading times in milliseconds; ms = milliseconds

Figures 4.1a+b Mean reading times of participants with and without dyslexia per region and per condition. Raw reading times are shown on the y-axis in milliseconds. Regions of interest are shown on the x-axis.

Figure 4.2a.

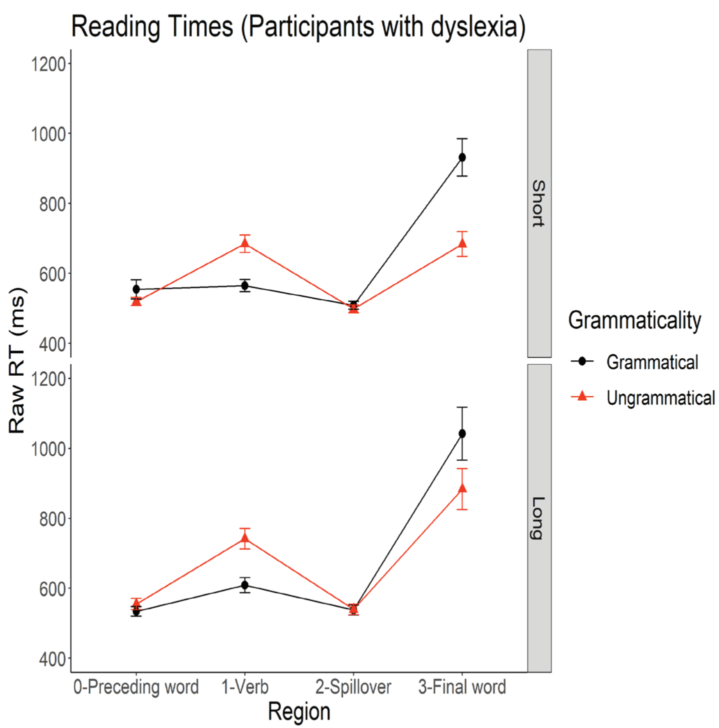
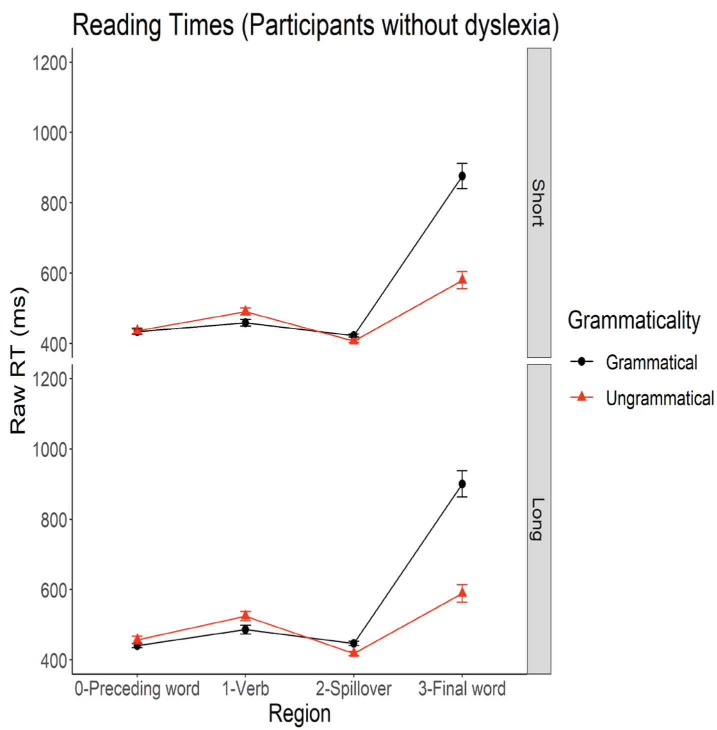


Figure 4.2b.



Note: RawRT = raw reading times in milliseconds; ms = milliseconds; Short = short distance; Long = long distance.

Figures 4.2a+b Mean reading times of participants with and without dyslexia per region for the factors Distance and Grammaticality. Raw reading times are shown on the y-axis in milliseconds. Regions of interest are shown on the x-axis.

Table 4.5 Fixed-effects results of the reading times (per region of interest) of adults with dyslexia, rounded to two decimal points.

	Adults with dyslexia															
	Baseline				Region 1 – Verb				Region 2 – Spill-over				Region 3 – Final word			
	Est. (*SE*)	*t*	*p*	±95% CI	Est. (*SE*)	*t*	*p*	±95% CI	Est. (*SE*)	*t*	*p*	±95% CI	Est. (*SE*)	*t*	*p*	±95% CI
Intercept	6.22 (0.04)	141.4	< .001 ***	(6.13 6.3)	6.34 (0.06)	104.61	< .001 ***	(6.22, 6.47)	6.16 (0.04)	166.5	< .001 ***	(6.09, 6.24)	6.51 (0.08)	85.49	< .001 ***	(6.36, 6.66)
Distance	-0.01 (0.01)	-1.36	.17	(-0.03, 0.01)	-0.03 (0.01)	-2.57	.01**	(-0.05, -0.01)	-0.02 (0.01)	-3.05	.002 ***	(-0.04, -0.01)	-0.04 (0.02)	-2.89	.004 ***	(-0.08, -0.01)
Gram.	0.00 (0.01)	-0.22	.83	(-0.02, 0.01)	-0.07 (0.01)	-6.6	< .001 ***	(-0.09, -0.05)	0.02 (0.01)	2.69	.007 ***	(0.01, 0.03)	0.11 (0.02)	7.38	< .001 ***	(0.08, 0.15)
Gram. × Distance	0.01 (0.01)	1.59	.11	(0.00, 0.03)	0.00 (0.01)	0.1	.92	(-0.02, 0.012	0.00 (0.01)	0.5	.614	(-0.01, 0.02)	0.03 (0.02)	1.8	.07	(0.00, 0.06)

Note: Est. = Estimate; *SE* = standard error; *t* = *t*-value; *p* = *p*-value; CI = confidence interval; Gram. = Grammaticality.

Table 4.6 Fixed-effects results of the reading times (per region of interest) of adults without dyslexia, rounded to two decimal points.

	Adults without dyslexia															
	Baseline				Region 1 – Verb				Region 2 – Spill-over				Region 3 – Final word			
	Est. (*SE*)	*t*	*p*	±95% CI	Est. (*SE*)	*t*	*p*	±95% CI	Est. (*SE*)	*t*	*p*	±95% CI	Est. (*SE*)	*t*	*p*	±95% CI
Intercept	6.02 (0.03)	197.7	< .001 ***	(5.96 6.08)	6.09 (0.04)	166.4	< .001 ***	(6.01, 6.16)	5.99 (0.02)	290.85	< .001 ***	(5.95, 6.03)	6.34 (0.04)	142.98	< .001 ***	(6.25, 6.42)
Distance	-0.02 (0.00)	-3.68	< .001 ***	(0.03, -0.01)	-0.02 (0.01)	-3.41	< .001 ***	(-0.03, -0.01)	-0.01 (0.00)	-3.4	< .001 ***	(-0.02, -0.01)	0.01 (0.01)	-0.7	.482	(-0.03, 0.01)
Gram.	0.00 (0.00)	-0.66	.51	(-0.01, 0.01)	0.03 (0.01)	-4.64	< .001 ***	(-0.04, -0.02)	-0.03 (0.00)	7.42	< .001 ***	(0.02, 0.04)	0.18 (0.01)	17.93	< .001 ***	(0.16, 0.2)
Gram. × Distance	0.00 (0.00)	0.67	.503	(-0.01, 0.01)	0.00 (0.01)	0.34	.735	(-0.01, 0.01)	-0.01 (0.00)	-1.34	.179	(-0.01, 0.00)	0.00 (0.01)	-0.09	.928	(-0.02, 0.02)

Note: Est. = Estimate; *SE* = standard error; *t* = *t*-value; *p* = *p*-value; CI = confidence interval; Gram. = Grammaticality.

4.3.2.1 Adults with Dyslexia

4.3.2.1.1 Baseline: Preceding Word

There were no significant fixed-effects of either Distance or Grammaticality, nor an interaction between them (see Table 4.5). Hence, there were no differences in RTs between sentences in the short and long condition, as well as grammatical and ungrammatical sentences in the group of adults with dyslexia.

4.3.2.1.2 Region 1: Verb

The model yielded significant fixed-effects of both Distance and Grammaticality (see Table 4.5). There was no interaction effect between Distance and Grammaticality. Adults with dyslexia read the verb in the long condition slower than the verb in the short condition. Furthermore, adults with dyslexia had longer RTs for the verb in ungrammatical than in grammatical sentences.

4.3.2.1.3 Region 2: Spill-Over

Significant fixed-effects of both Distance and Grammaticality emerged, but there was no interaction effect between the two (see Table 4.5). Adults with dyslexia read the spill-over region in the long condition slower than in the short condition. Also, adults with dyslexia read the spill-over region in grammatical sentences slower than in ungrammatical sentences.

4.3.2.1.4 Region 3: Final Word

For the final region of interest, the model revealed significant fixed-effects of Distance and Grammaticality. The interaction effect between Distance and Grammaticality was only marginally significant (see Table 4.5). Thus, participants with dyslexia displayed longer RTs for the final word in the long than in the short condition. Also, participants with dyslexia displayed longer RTs for the final word in grammatical sentences than ungrammatical sentences.

4.3.2.2 Adults without Dyslexia

4.3.2.2.1 Baseline: Preceding Word

There was a significant fixed-effect of Distance for this region. No other factor proved significant; no significant interactions between the factors were observed (see Table 4.6). Thus, participants without dyslexia took longer to read the noun in the long condition than in the short condition in this region.

4.3.2.2.2 Region 1: Verb

The model yielded significant fixed-effects of Distance and Grammaticality (see Table 4.6). No significant interaction between the factors emerged. Participants without dyslexia read the verb in the long condition slower than the verb in the short condition. Furthermore, adults without dyslexia had longer RTs for the verb in ungrammatical than in grammatical sentences.

4.3.2.2.3 Region 2: Spill-Over

Significant fixed-effects of Distance and Grammaticality emerged for this region (see Table 4.6). However, there were no significant interaction effects. Overall, participants without dyslexia took longer to read the Spill-over region following the verb in the long than in the short condition. Moreover, adult without dyslexia read the Spill-over region faster in ungrammatical than in grammatical sentences.

4.3.2.2.4 Region 3: Final Word

For the final word in the sentence, we saw a significant fixed-effect of Grammaticality. No other factor proved significant; there was no interaction between the factors (see Table 4.6). Overall, participants without dyslexia read the final word slower in grammatical than in ungrammatical sentences.

4.3.3 Summary of Results

The first research question was whether there was a difference between participants with and without dyslexia in overall accuracy on the **grammaticality judgement task**. In line with our prediction, adults with dyslexia performed worse overall on the grammaticality judgement task than participants without dyslexia.

The second research question was whether adults with dyslexia showed a difference in judging the accuracy of sentences between the short and long conditions, as well as grammatical and ungrammatical sentences on the grammaticality judgement task. Against our prediction, there was no difference in accuracy for sentences in the short- and long-distance conditions. Again, against our prediction, we did not see a difference in accuracy between grammatical and ungrammatical sentences. We also observed no interaction between distance and grammaticality.

The third research question was whether distance and grammaticality affected the RTs of the three regions of interest (i.e., verb, spill-over and final word) for adults with dyslexia and adults without dyslexia. In line with our prediction, we found that participants with dyslexia had longer RTs for the verb, the spill-over and the final word in the long than in the short condition. Furthermore, against our prediction, participants with dyslexia read the verb slower in ungrammatical sentences, but read the spill-over and the final word slower in grammatical sentences. No effects of distance and grammaticality emerged for the baseline in adults with dyslexia.

For participants without dyslexia, we found longer RTs for the verb and the spill-over in the long than in the short condition. Participants without dyslexia also read the verb slower in ungrammatical than in grammatical sentences, while they read the spill-over and the final word slower in grammatical than ungrammatical sentences. Both of these findings are partly in line with our prediction. Also, participants without dyslexia took longer to read the noun in the baseline in the long condition than in the short condition. See Table 4.7 for an overview of RT results per region of interest for the two groups.

Table 4.7 Summary of RT results per group and per region of interest.

	Baseline		**Region 1 Verb**		**Region 2 Spill-over**		**Region 3 Final word**	
	DYS	***NDYS***	***DYS***	***NDYS***	***DYS***	***NDYS***	***DYS***	***NDYS***
Distance	***x***	***Long > short***	Long > short	Long > short	Long > short	Long > short	***Long > short***	**x**
Gramma.	x	x	Ungram. > gram.	Ungram. > gram.	Gram. > ungram.	Gram. > ungram.	Gram. > ungram.	Gram. > ungram.
Gramma. x Distance	x	x	x	x	x	x	x	x

Note: RT = reading time(s); Gramma. = Grammaticality; DYS = adults with dyslexia; NDYS = adults without dyslexia; x = no effect; long = long condition; short = short condition; ungram. = ungrammatical sentences; gram. = grammatical sentences; long > short = longer RTs for long than short condition; ungram. > gram. = longer RTs for ungrammatical than grammatical sentences. The effects that showed a different pattern across the two groups are presented in bold.

4.4 Discussion

The current study investigated the processing of linear distance, as a measure of working memory (WM) load, in sentences containing subject-verb (dis)agreement in Dutch adults with and without dyslexia using a self-paced reading (SPR) task. The main goal of the study was to examine the processing of linear distance within the group with dyslexia and compare it qualitatively to the group without dyslexia. In order to do so, we investigated participants' accuracy on the grammaticality judgement task, as well as their RTs of the three critical regions during real-time sentence processing.

4.4.1 Accuracy on the Grammaticality Judgement Task

4.4.1.1 Group Differences

Our **first research question** was whether adults with and without dyslexia differed in their overall accuracy on the grammaticality judgement task. In line with our prediction, adults with dyslexia had an overall lower accuracy than adults without dyslexia on this task. Although there is no previous literature on the performance of adults with dyslexia on an SPR grammaticality judgement task, these results are in line with those of previous ERP studies using a grammaticality judgement task, which revealed differences between the two groups in reading (e.g., Miller-Shaul, 2005; Rüsseler et al., 2007; our Chapter 3) and listening (e.g., Cantiani et al., 2013a; our Chapter 2; but see: Rispens et al., 2006). However, it bears repeating that, although participants with dyslexia performed more poorly relative to participants without dyslexia, both groups exhibited a close-to-ceiling performance on this task (similar to our results for adults with dyslexia reported in Chapters 2 and 3).

4.4.1.2 Adults with Dyslexia

Our **second research question** was whether adults with dyslexia displayed a difference in judging the accuracy of sentences in the short and long condition, as well as grammatical and ungrammatical sentences on the grammaticality judgement task. We predicted that adults with dyslexia would show more errors on judging the accuracy of sentences in the long than in the short condition due to an increase in linear distance (i.e., WM load) in long sentences. However, we did not see a difference in the accuracy of short or long linear distance sentences. These results are contrary to previous research that has reported lower accuracy for longer linear distance sentences in adults without dyslexia (e.g., Kaan, 2002; Rispens & de Amesti, 2017). Furthermore, our results do not support the DLT (Gibson, 1998, 2000), which predicts that the long condition would incur a higher processing cost reflected in lower accuracy on this condition. We also based our prediction on the proposal that WM impairments are one of the causes of morphosyntactic processing difficulties in individuals with dyslexia, both in written comprehension (Stella & Engelhardt, 2019; Wiseheart et al., 2009) and the comprehension of spoken sentences (Robertson & Joanisse, 2010). However, these studies did not use a grammaticality judgement task, but a sentence comprehension task, which could explain the discrepancies between our results and these previous findings. For instance, Robertson and Joanisse (2010) included comprehension questions after each sentence, in which they posed a question related to the material presented between the subject and the verb. Thus, participants were forced to pay more attention to the intervening material, alongside detecting and tracking the features of the subject and the verb, in order to answer a question correctly. It is also possible that the choice of SPR as our method influenced the results and that reading as presentation modality places an additional burden on adults with dyslexia when judging sentence grammaticality accuracy, regardless of linear distance.

Furthermore, adults with dyslexia showed no difference in judging the accuracy of grammatical and ungrammatical sentences. This result is against our prediction that adults with dyslexia will show a poorer performance on judging ungrammatical than grammatical sentences. In fact, adults with dyslexia perform above chance in judging the accuracy of both grammatical and ungrammatical sentences, albeit not as successfully as adults without dyslexia (see Table 4.2). Thus, adults with dyslexia seem to be less sensitive to the inflectional features of the subject and the verb than adults without dyslexia (e.g., Cantiani et al., 2013a). However, due to the mixed results of previous studies with grammaticality judgements in adults with dyslexia, this question warrants further investigation.

Finally, despite adults with dyslexia failing to show an influence of linear distance on the grammaticality judgement task, they showed poorer performance than adults without dyslexia on all the WM and STM behavioral measures (i.e., simple and complex digit span tasks; and non-word repetition). This discrepancy could have occurred for several reasons. First, it might be that linear distance is not dependent on WM, at least as described in Baddeley's (1986) framework. This notion is echoed in a study by Caplan and Waters (1999), who instead propose the existence of a separate memory mechanism that is responsible solely for syntactic parsing. An alternative interpretation is that sentence processing does not crucially rely on WM (e.g., Martin, 1993), or that the WM mechanism used in sentence processing is at least partly separate from that measured by behavioral tests of WM capacity (e.g., Waters & Caplan, 2004). According to Caplan and Waters (1999), syntactic processing and traditional WM tests (e.g., digit span tasks) do not compete for the same WM resources. More specifically, syntactic parsing relies on automatic processes, while digit span tasks draw on consciously controlled mechanisms. Thus, the existence of a dedicated WM mechanism for syntactic parsing, or the separation of resources for syntactic parsing and traditional WM measures, such as digit span tasks, could explain the absence of an effect for long distance in our study.

It could also be that syntactic complexity (i.e., the complexity of syntactic structures under investigation), rather than linear distance, is a better measure of WM load. In that case, adults with dyslexia might show lower accuracy on syntactically more complex sentences, such as relative clauses and passives (e.g., Stella & Engelhardt, 2019; Wiseheart et al., 2009) than on the stimuli used in the current study. Furthermore, although the experiment included filler sentences, as well as experimental sentences that were balanced as much as possible, participants could have nonetheless developed a strategy when reading sentences. In order to control for such an occurrence, further research could include a comprehension question related to the intervening material between the subject and the verb, rather than a grammaticality judgement question (similar to Robertson & Joanisse, 2010).

4.4.2 Reading Times

The third research question was whether distance and grammaticality affected the RTs of the three regions of interest (i.e., verb, spill-over and final word) for participants with and without dyslexia.

4.4.2.1 Linear Distance

In line with our prediction, participants with dyslexia read the verb, the spill-over and the final word slower in the long than in the short condition. The results of RTs for adults with dyslexia confirm DLT's (Gibson, 1998, 2000) hypothesis and the results of previous SPR research (e.g., Bartek et al., 2011; Grodner & Gibson, 2005; Liu & Wang, 2019), which showed that longer linear distance between the subject and the verb increases integration difficulty at the integration point in the sentence (i.e., in our case, the verb). In our study, the increase in integration difficulty for adults with dyslexia was, thus, likely caused by an increase in WM load in the long than in the short condition, as predicted. Our results are similar to those of Kaan (2002) and Vos et al. (2001), who did not see a difference between the condition with a higher WM load and the condition with a lower WM load on a grammaticality judgement task, but only observed differences at the ERP level for adults without dyslexia. Thus, we can assume that both RTs on an SPR task and ERPs are a more sensitive measure of agreement violation processing than the behavioral grammaticality judgement task. Finally, our results contradict those of Liu and Wang (2019), who reported that an increase in linear distance leads to lower accuracy, but an increase in structural distance leads to longer RTs on a SPR task. In our study, an increase in linear distance did not yield lower accuracy for adults with dyslexia on the grammaticality judgement task, but it did cause longer RTs for the regions of interest in long versus short condition. Although Liu and Wang (2019) used a different population (i.e., older adults; mean age = 62.83) and different stimuli (i.e., relative clauses), both adults with dyslexia and older adults exhibit WM problems, which is why we believed that these previous results could be generalized to the current study. However, our study did not include a manipulation of structural distance. Thus, more research is needed to disentangle the unique contributions of linear and structural distance in sentence processing in adults with dyslexia.

Meanwhile, our participants without dyslexia showed longer RTs in the long compared to the short distance condition only for the verb and the spill-over, but not the final word. These results are partly in line with the DLT (Gibson 1998, 2000). Thus, linear distance only seemed to play a role for the integration point and the spill-over region in adults without dyslexia. Furthermore, the absence of an effect of distance for the final word in adults without dyslexia could indicate that they do not need extra time to integrate the information while reading the final word. However, unlike adults with dyslexia, adults without dyslexia displayed longer RTs for the noun preceding the verb (i.e., baseline) in the long condition. This could be an expectancy effect: adults without dyslexia might build up expectation of the verb in the long condition, which could be reflected in the longer RTs for the noun preceding the verb.

In summary, the results of RTs for the linear distance manipulation in our experiment are partly in line with DLT (Gibson, 1998, 2000). More specifically, while both adults with and without dyslexia are affected by the increase in linear distance between the subject and the verb, adults without dyslexia do not show an influence of the long linear distance, associated with higher syntactic integration costs, for the final word.

4.4.2.2 Grammaticality

An interesting finding of our study is that both groups of participants displayed the same RT pattern in the three regions of interest when it comes to grammaticality. Thus, both participants with and without dyslexia read the verb slower in ungrammatical sentences than grammatical sentences, but read the spill-over and the final word slower in grammatical sentences. Following DLT (Gibson, 1998, 2000), we assumed that longer RTs are associated with an increased difficulty of integrating the verb in the sentence context. Thus, for both groups of participants, our results present evidence for both locality effects and the slowdown in RTs for the verb in ungrammatical sentences (in line with DLT; Gibson, 1998, 2000), and anti-locality effects and the speedup for the spill-over and the final word regions in grammatical sentences (e.g., Levy, 2008).

A possible explanation for the RT asymmetry (i.e., longer RTs for the verb in ungrammatical sentences vs. the longer RTs of the spill-over and the final word regions in grammatical sentences) is that both groups of participants are trying to minimize the WM load in ungrammatical sentences. Once they read the verb, we assume that participants with and without dyslexia were likely trying to read the regions following the verb faster in ungrammatical sentences in order to eliminate the WM demands by providing an answer to the grammaticality judgement question as quickly as possible (in line with Van Dyke & McElree, 2006). A similar finding for low-reading span readers compared to high-reading span readers was reported by King and Just (1991). Although the authors used comprehension questions rather than a grammaticality judgement task, they found that low-span readers were reading sentences with a higher WM load faster. They concluded that this strategy occurred because "participants tried to rush through the sentence in order to recall sooner the memory load materials" (p. 589).

Lastly, since both participants with and without dyslexia read the verb in ungrammatical sentences slower than in grammatical sentences, we can conclude that both groups of participants are sensitive to subject-verb disagreement at the integration point in the sentence, in line with DLT (Gibson, 1998, 2000).

4.5 Conclusion

The current study is the first SPR study on the processing of linear distance in subject-verb (dis)agreement in adults with and without dyslexia. Although both groups performed close-to-ceiling on accuracy, our results revealed poorer accuracy for participants with dyslexia than participants without dyslexia on the grammaticality judgement task. However, there was no evidence that adults with dyslexia were influenced by linear distance or ungrammaticalities on the grammaticality judgement task. Both adults with and without dyslexia showed longer RTs for the integration point (i.e., verb) and the spill-over in the long than short condition, in line with the DLT (Gibson, 1998, 2000). However, only adults with dyslexia exhibited longer RTs for the final word in the long than in the short condition, which are associated with syntactic integration difficulty at the end of the sentence. An interesting anti-locality mechanism (i.e., longer RTs at/after the integration point; e.g., Levy, 2008) was used by both participants with and without dyslexia in ungrammatical sentences. More specifically, both groups of participants seem to go more quickly through ungrammatical sentences after reaching the integration point in order to disengage the working memory load by answering the grammaticality judgement question. Furthermore, partly in line with DLT (Gibson, 1998, 2000), we found that an increase in linear distance led to longer RTs at the integration point and the regions following it in sentences with a long distance between the subject and the verb, rather than lower accuracy, in the group with dyslexia.

In sum, the present study presents evidence for both locality effects (DLT; Gibson, 1998, 2000) and anti-locality effects (e.g., Levy, 2008) in adults with and without dyslexia. Finally, we demonstrate that SPR is a sensitive method for detecting subtle differences in processing agreement violations in adults with and without dyslexia. Future research using methods that are sensitive to different aspect of real-time processing (e.g., ERPs or eye-tracking) could completement our RT and accuracy data and shed more light on WM demands, as well as the sensitivity of adults with dyslexia to integration difficulty and agreement violations.

CHAPTER 5

General Discussion and Conclusions

5.1 Overview

The overall aim of this thesis was to investigate within-phrase gender and number (dis)agreement processing, as well as across-phrase subject-verb (dis) agreement processing in in adults with dyslexia. The original plan was to investigate all of these using ERP experiments, but this could not be achieved because of the COVID-19 pandemic. Hence, for the study on subject-verb (dis)agreement, we used a self-paced-reading (SPR) paradigm. We also used behavioral grammaticality judgements in all three studies to explore whether the subtle agreement processing differences between adults with and without dyslexia could be captured by the behavioral measures, or, as previously reported (e.g., Rispens et al., 2006), only with the use of more sensitive online measures, such as ERPs (and SPR). In addition to the temporal aspects of agreement violation processing and the differences between online and offline behavior of adults with and without dyslexia, we were interested in exploring how the modality of presentation in ERP studies (listening vs. reading) influences gender and number (dis)agreement processing in adults with dyslexia. Our final goal was to compare within-phrase (gender and number disagreement) and across-phrase (subject-verb disagreement) processing in adults with dyslexia. In this chapter, we will address the research questions from the general introduction in relation to the findings from the three experiments presented in this thesis. Next, we will present the general conclusions and avenues for future research, followed by implications for remediation and accommodations.

5.2 Research Questions

5.2.1 Research Question 1: Is there a difference between adults with and without dyslexia on a behavioral grammaticality judgement task?

We saw a difference in performance between adults with and without dyslexia on the behavioral grammaticality judgement task in all three studies. Overall, both adults with and without dyslexia performed close-to-ceiling, but adults with dyslexia still performed more poorly than adults without dyslexia on these tasks. Thus, unlike in the study of Rispens et al. (2006), the difference between adults with and without dyslexia was not only visible with the use of ERPs, but also on behavioral grammaticality judgements. Additionally, these group differences were stable and visible both in listening (Chapter 2) and reading (Chapters 3 and 4), on the behavioral task that accompanied ERP measurements (Chapters 2 and 3) and SPR (Chapter 4), with different stimuli (gender and number disagreement: Chapters 2 and 3; subject-verb disagreement: Chapter 4), with a different proportion of grammaticality judgement questions (20% of the stimuli:

Chapters 2 and 3; 100% of the stimuli: Chapter 4) and under slightly different task demands (three seconds to answer the judgement question: Chapters 2 and 3; no time limit: Chapter 4). Therefore, we can conclude that differences between adults with and without dyslexia on the behavioral grammaticality judgement task are not influenced by the experimental manipulations, including modality of presentation. Our research adds to the growing body of evidence which shows that individuals with dyslexia perform more poorly than typical readers on a morphosyntactic grammaticality judgement task across the lifespan (children: Leikin & Assayag- Bouskilla, 2004; Rispens & Been, 2007; Rispens et al., 2004; adults: Cantiani et al., 2013a; Rüsseler et al., 2007; but see: children: Cantiani et al., 2015; Sabisch et al., 2006; adults: Cantiani et al., 2013a; Rispens et al., 2006; for no differences between the groups on this task).

We can conclude that the behavioral grammaticality judgement task is sensitive enough to capture general group differences between adults with and without dyslexia, with adults with dyslexia performing overall worse than adults without dyslexia. However, not all participants with dyslexia performed worse than all adults without dyslexia. Furthermore, since both groups exhibited close-to-ceiling performance, we cannot claim that these group differences are indicative of an agreement violation processing impairment in adults with dyslexia. Instead, adults with dyslexia seem to be less sensitive, rather than insensitive, than adults without dyslexia to agreement violations and inflectional morphology, similar to previous findings (Cantiani et al., 2013a, 2013b; Rispens et al., 2006; Rüsseler et al., 2007).

5.2.2 Research Question 2: Does the neurophysiological pattern (as measured with ERPs) during processing of morphosyntactic information differ between adults with and without dyslexia?

We found differences in the ERP patterns between adults with and without dyslexia in response to gender and number disagreement in both the auditory and the visual modality. In listening, there were qualitative differences between the two groups, whereas temporal and topographic differences between the groups emerged in reading. More specifically, in listening, there was no ERP effect present for gender disagreement for adults with dyslexia, whereas a frontal negativity was elicited in response to number disagreement. For adults without dyslexia, listening to sentences containing gender disagreement elicited a LAN and a P600, while number disagreement elicited only a P600 (Popov, 2017). For adults with dyslexia, reading sentences containing gender disagreement elicited a P600, while sentences with number disagreement elicited a frontal negativity and a P600. A P600 was elicited for both gender and number disagreement for adults without dyslexia in the visual modality (Popov & Bastiaanse, 2018). Although the results of our listening study on adults with dyslexia should be interpreted with caution due to a small sample size, we nevertheless saw differences between the two groups regardless of the modality of presentation. We can thus conclude that adults with dyslexia process agreement violations using ERPs differently from adults without dyslexia. These results confirm previous reports of ERP differences between adults with and without dyslexia in response to subject-verb agreement violations (Cantiani et al., 2013a, 2013b; Rispens et al., 2006). Therefore, ERPs emerged as a sensitive measure of agreement violation processing differences between adults with and without dyslexia.

However, unlike previous studies (e.g., Cantiani et al., 2013a, 2013b), we do not claim that the atypical processing of agreement violations exhibited by adults with dyslexia should necessarily be classified as a morphosyntactic processing impairment in dyslexia. In both reading and listening, we saw that adults with dyslexia typically notice the violation (exhibited by the P600 in reading and a frontal negativity in listening). The absence of an ERP effect for adults with dyslexia in response to gender disagreement in listening could be due to ERP effects in listening being smaller than in reading and the smaller sample size of our participant group. Thus, adults with dyslexia seem to be less sensitive to agreement violations than adults without dyslexia, and if they notice them, they do so with a delay. Our behavioral and ERP results suggest that adults with dyslexia do not only exhibit slower speed of processing, but also more shallow processing of agreement violations than adults without dyslexia. This is in line with the *good-enough parsing* account (Ferreira et al., 2002; Ferreira & Patson, 2007), according to which individuals accept an incomplete (i.e., 'good-enough') sentence representation instead of re-analyzing the sentence in order to build a complete and thorough sentence representation when encountering a violation.

The question that remains is what causes the atypical processing of agreement violations in adults with dyslexia. Coming back to the theories of morphosyntactic processing in dyslexia, we found support for Byrne's (1981) idea that individuals with dyslexia exhibit a less mature or less deep level of linguistic processing. However, unlike Byrne (1981), we did not investigate phonological processing in dyslexia and we cannot claim that morphosyntactic difficulties in dyslexia are independent of an underlying phonological deficit. These group differences could be driven by specific morphosyntactic processing difficulties, an underlying phonological processing deficit, or by a general linguistic processing weakness. Thus, more research is needed to establish the exact cause(s) of these morphosyntactic processing difficulties. Finally, our results corroborate the findings of an atypical electrophysiological pattern in adults with dyslexia compared to adults without dyslexia for other ERP components (e.g., the N400: Rüsseler, et al., 2007; the MMN: Schulte-Körne et al., 2001; N1: Van Setten et al., 2016).

5.2.3 Research Question 3: Is there a processing difference between reading and listening to the same stimuli for adults with dyslexia?

Using ERPs, we found that the modality of presentation did play a role in agreement violation processing in adults with dyslexia. More specifically, we found that they showed a delayed P600 in reading in response to both gender and number agreement violations, as well as a late frontal negativity for number agreement violations (Chapter 3). In contrast, in listening, no ERP effect was elicited for gender agreement violations, while a LAN-like frontal negativity emerged in response to number violations (Chapter 2). Thus, different modalities elicited different ERP effects. However, it bears mentioning that gender and number disagreement elicited a slightly different ERP pattern for reading and listening in adults without dyslexia as well (Popov, 2017). More specifically, a LAN was present for listening in adults without dyslexia, but not in reading, while the P600 was present in both modalities (Popov, 2017). If we assume that reading and listening rely on the same processing mechanism, then identical components should be elicited in both modalities (Friederici et al., 1993; but see: Hagoort & Brown, 2000, who elicited the LAN in almost all conditions in listening, but not in reading the same stimuli). Therefore, it is possible that reading and listening do not entail exactly the same processes in either typical readers or adults with dyslexia. Another possibility is that the LAN is influenced by the timing difference between reading and listening (Popov, 2017), which can explain why a LAN-like component (i.e., frontal negativity) was elicited in response to both number disagreement in listening (700-900 ms time window) and reading (800-1000 ms time window), for adults with dyslexia. Our results do not enable us to conclude whether one modality is easier than the other for adults with dyslexia, since the results of the listening study have limited generalizability and need to be interpreted with caution due to a small sample size. However, the finding of a P600 in response to written agreement violations indicates that reading as the presentation modality was not more impaired than listening in our sample of adults with dyslexia. This result has important theoretical and methodological implications for future ERP studies on adults with dyslexia, which will be discussed in more detail in Section 5.3. below.

5.2.4 Research Question 4: Is there a difference between within-phrase and across-phrase disagreement processing for adults with dyslexia?

In our ERP experiments, we observed that adults with dyslexia exhibit slower processing of within-phrase disagreement (i.e., article-noun and adjective-noun disagreement), as exhibited by a delay in the onset or longer duration of the ERP components in adults with dyslexia. In the SPR experiment, we also saw that adults with dyslexia process subject-verb disagreement across-phrase slower than adults without dyslexia in terms of reading times (RTs). In the ERP experiments, we measured at the critical word (noun), while in the SPR experiment we recorded RTs for the critical word (the verb) and the two regions following it (spill-over and the final word). Although we cannot directly compare our within-phrase ERP and across-phrase SPR results due to different methodologies used, it appears that there are no large differences between within-phrase and across-phrase disagreement processing for adults with dyslexia. However, it might be that disagreement processing is influenced more by the methodology used. For instance, SPR data revealed some interesting processes when encountering agreement violations used by adults with dyslexia, which were not visible using ERPs in our other experiments. More specifically, adults with dyslexia required more time to read the verb in sentences in the short- than in the long-distance condition during subject-verb (dis)agreement processing. Furthermore, adults with dyslexia took longer to read the final word in the short- than the long-distance disagreement condition – a finding that was not present for adults without dyslexia. This result suggests that adults with dyslexia require more time for morphosyntactic integration at the end of the sentence, which is a region that is typically excluded from ERP experiments. Altogether, while we can tentatively conclude that agreement type does not seem to play a role in an online task, future research is needed to disentangle this question using the same methodology.

5.3 General Conclusions

Our research has theoretical and methodological implications for linguistic studies in general, and for studies on morphosyntactic agreement violation processing in dyslexia in particular. First, we showed that difficulties with morphosyntactic processing in dyslexia persist into adulthood and that speed is more affected than accuracy. These results are consistent with those of Callens et al. (2012), who reported the same for university students with dyslexia on all reading and writing tasks, with the exception of spelling.

In particular, ERPs and SPR emerged as a more sensitive measure of morphosyntactic processing in adults with dyslexia than behavioral grammaticality judgements. Overall, the studies presented in this thesis indicate that adults with dyslexia are overall less sensitive to agreement violations than adults without dyslexia and they process them with a delay. Consequently, based on our findings, we argue that subtle morphosyntactic difficulties are present in adults with dyslexia.

Our research also has methodological implications. In the ERP reading experiment, we elicited a P600 in response to written stimuli containing gender and number disagreement, similar to the P600 reported for adults with dyslexia in auditorily presented sentences (e.g., Rispens et al., 2006). Additionally, we showed that there was a difference between reading and listening to the same stimuli in adults with dyslexia in terms of ERPs. Therefore, future studies should investigate agreement violation processing in both modalities to ascertain that the observed effects are not modality-specific. A puzzling finding of a frontal negativity for adults with dyslexia emerged in the late time windows in both of our ERP studies, indicating that the effect was not caused by the modality of presentation. While we assume that this negativity is likely related to the onset of the following word, the issue of the exact functional interpretation of this late frontal negativity deserves more attention.

Finally, all three studies revealed that the temporal aspects of agreement violation processing are affected in adults with dyslexia. Adults with dyslexia appeared not only to require more time, but also to integrate morphosyntactic information at the end of a sentence, as shown by the SPR experiment. Although accuracy on the grammaticality judgement task was high for both adults with and without dyslexia, our ERP and SPR data confirm that real-time agreement violation processing (and as a result, sentence processing) in adults with dyslexia is not typical.

5.4 Implications for Remediation and Accommodations

In addition to the theoretical and methodological implications mentioned in the previous section, our research has implications for remediation of and accommodations for dyslexia. For instance, if we see an atypical pattern of morphosyntactic processing in adults with dyslexia, then this suggests that remediation of morphosyntactic difficulties should be carried out with children with dyslexia in order to overcome linguistic processing problems later in life. However, more research is needed to ascertain the causes of morphosyntactic processing difficulties in dyslexia that need to be addressed through remediation. Moreover, in our studies, we saw a delay in agreement violation processing at the level of single words. If these subtle difficulties are found in controlled online experiments, in which only one word is presented at a time, it is likely that sentence processing in a more naturalistic environment, in which more complex sentences and longer texts are presented, is even more problematic for adults with dyslexia (Robertson & Gallant, 2019). The issue of additional time needed for language processing is particularly relevant for accommodations provided to university students with dyslexia. Currently, university students with dyslexia in The Netherlands are typically provided with ten extra minutes for every hour of an exam, while university students in the UK are provided with up to 25% extra time for taking exams (Engelhardt, 2020). However, there are no systematic studies that quantified the exact additional time needed for adults with dyslexia and our findings on the delay in agreement violation processing in dyslexia confirm that further research in this area is needed.

5.5 Future Directions

Future research could expand on the studies described in this thesis in important ways. For instance, we did not investigate whether morphosyntactic processing difficulties in adults with dyslexia are caused by a phonological deficit. Dyslexia is a heterogenous impairment (Pennington, 2006) and a phonological deficit cannot explain all symptoms in all cases of dyslexia (Castles & Friedmann, 2014; Van Bergen et al., 2014). Thus, more studies on the causes – phonological or otherwise – of morphosyntactic processing difficulties in dyslexia are warranted. Furthermore, in all three studies in this thesis, adults with dyslexia showed almost an identical performance on the grammaticality judgement task, regardless of the different experimental manipulations. Therefore, more research is necessary to determine the extent to which cognitive, linguistic and other factors (including reading experience) influence participants' performance on this task.

Since we confirmed that a P600 is elicited in adults with dyslexia in response to written morphosyntactic agreement violations in a sentential context, future studies should explore written agreement violation processing in adults with dyslexia, not only focusing on different types of agreement, but also on other linguistic violations. In particular, more research is needed on the processes underlying the P600 (i.e., repair, reanalysis, and integration), since our research on the structural repair processes of the P600 in dyslexia was inconclusive.

The results of our ERP listening study have limited generalizability due to a small sample size of participants with dyslexia. Future studies should include a larger sample size to ascertain the differences between reading and listening as the modality of presentation in adults with dyslexia using ERPs. In particular, more research is needed on the nature of the frontal negativities that seem to be commonly elicited in individuals with dyslexia in response to agreement violations (our reading and listening ERP studies on adults with dyslexia; listening studies on children with dyslexia: Cantiani et al., 2015; Sabisch et al., 2006).

The current studies show that ERP and SPR methodologies are more sensitive than behavioral tasks in identifying group differences between individuals with and without dyslexia. Therefore, more research should be done on how these methodologies can help identify individual differences between individuals with and without dyslexia, which is particularly useful for studying the effects of reading interventions (see, e.g., Hasko et al., 2014; Kujala et al., 2001).

It is generally assumed that the adverse effect of reduced reading experience is diminished in a sample of university students with dyslexia (e.g., Raveh & Schiff, 2008; Wiseheart et al., 2009). However, we did not directly investigate reading experience and whether it influenced participants' performance in our reading studies, or on the behavioral grammaticality judgement task. Further research on this topic is needed.

In Chapter 4, we investigated the influence of linear distance as a measure of working memory (WM) load on subject-verb (dis)agreement processing in adults with dyslexia in an SPR study. Future studies could explore the influence of structural distance (number of intervening syntactic nodes) and compare the two types of distance in a single study (similar to the eye-tracking study by Liu & Wang, 2019). Following Robertson and Joanisse (2010), future studies could use comprehension questions pertaining to the material intervening between the subject and the verb, rather than end-of-sentence grammaticality judgement questions, in order to burden the participants' WM load and eliminate any possibility of participants forming a reading strategy. The influence of the modality of presentation on the performance of adults with dyslexia in self-paced tasks can also be compared by using the same stimuli presented in the self-paced reading study to a self-paced listening study. Finally, the SPR stimuli used in the current study could be adapted to different methods (e.g., eye tracking or ERPs), or used for concurrent SPR and eye tracking, or SPR and ERP study, in order to gain more information regarding different aspects of agreement violation processing in adults with dyslexia.

APPENDIX A

Description of the Behavioral Measures
Used in the Experiments

The following tests were used in the experiments (per experiment/chapter):

Experiment 1 (Chapter 2):

- Word reading fluency
- Pseudo-word reading fluency
- Word spelling
- Spoonerisms
- Morphology & Syntax
- Reversals

Experiment 2 (Chapter 3):

- Word reading fluency
- Pseudo-word reading fluency
- Word spelling
- Reversals
- Morphology & Syntax

Experiment 3 (Chapter 4):

- Word reading fluency
- Pseudo-word reading fluency
- Word spelling
- Spoonerisms
- Morphology & Syntax
- Reversals
- Vocabulary
- Digit span tasks
- Letter-number sequencing
- Non-word repetition

These behavioral tests are described below.

Word reading fluency

Word reading fluency was assessed by using the One Minute Test (*Een-minuut test* – EMT; Tops et al., 2019). This test was tailored and validated for Dutch adults with dyslexia in higher education. Participants were asked to read single words aloud as quickly and accurately as possible from a list of 132 Dutch words of increasing length and difficulty. Participants had one minute to complete the task. The raw score was calculated as the number of correct words that the participants read within 1 minute.

Pseudo-word reading fluency

Pseudo-word reading fluency was assessed using The Klepel (Van den Bos et al., 1994). This test consisted of a list of 116 pseudo-words of increasing length and difficulty. Participants had to read aloud as many pseudo-words as possible according to Dutch orthographic and phonotactic rules. Participants were given one minute to complete the task by reading the pseudo-words as quickly and accurately as possible. The raw score was calculated as the number of correct pseudo-words that the participants read within one minute.

Word spelling

Word spelling was assessed through the spelling subtest of the Test voor Gevorderd Lezen en SCHrijven (GL&SCHR; De Pessemier & Andries, 2009), a dyslexia assessment battery for Dutch adolescents and adults. Participants were required to write down 30 Dutch words of increasing length and difficulty to oral dictation while their spelling time was being measured. Each word was only pronounced once and was not repeated. Participants were also required to choose one of the three options to indicate how certain they were of the correct spelling of the word: *onzeker* ('uncertain'), *bijna zeker* ('almost certain') and *heel zeker* ('very certain'). Raw score was calculated as the number of correctly spelled words. A weighted score was also calculated based on the level of uncertainty indicated for each word.

Morphology & Syntax

A sentence correction task, the Morphology and Syntax test from the GL&SCHR dyslexia assessment for Dutch (De Pessemier & Andries, 2009) was used to assess participants' knowledge of grammatical rules. Participants were provided with a list of 20 Dutch sentences and were told that almost all sentences contain an error. It was explained that this implies errors at the word or sentence level (e.g., errors with verb endings). Participants were instructed to read the sentences and to identify and correct the error. They were also told that the maximum number of errors per sentence is one, but that there are also sentences containing no errors. Participants also had to indicate how certain they were of their answer: *onzeker* ('uncertain'), *bijna zeker* ('almost certain') and *heel zeker* ('very certain'). The raw score was calculated as the number of accurate corrections of sentences. A weighted score was calculated based on the level of uncertainty for each sentence that participants had to correct.

Spoonerisms

A Spoonerisms test from the GL&SCHR (De Pessemier & Andries, 2009) was used to evaluate the phonological awareness of participants with dyslexia. Participants heard two words and had to switch the first letter of the first word with the first letter of the second word (e.g., *rode bal* became *bode ral*). A total of 20 word pairs (40 words) were orally presented and participants were not allowed to write down the words. Both the raw score and the time required to complete the task (i.e., provide an answer for each word pair) were computed. The raw score was calculated based on the number of correct answers for each word pair, while the percentile score was calculated based on the total time required for answers.

Reversals

A Reversals test ('Omkeren') from the GL&SCHR (De Pessemier & Andries, 2009) was used to evaluate phonological awareness of participants with dyslexia. In the test, participants were required to answer 'yes' or 'no' to the question of whether two words were reversals of each other or not (e.g., *pat – tap* are reversals of each other, whereas *kmer* and *premk* are not). A total of 20 word pairs (40 words) were orally presented and participants were not allowed to write down the words. Both a raw score and the time required to complete the task (i.e., provide an answer for each word pair) were computed. The raw score was calculated based on the number of correct answers for each word pair.

Vocabulary

Dutch vocabulary skills were assessed with a digitized version of the Vander Beken et al. (2018) administered via a Qualtrics survey (www.qualtrics.com). Participants were presented with 75 target words with four descriptions provided for each word and had to determine which description matches the meaning of the target word. Each correct answer was worth one point.

Digit span tasks

We used several digit span tasks (WAIS-IV-NL, Wechsler IV, 2012) to measure phonological short-term memory (**digit span forward**) and working memory (**digit span backwards** and **digit span sequencing.** In **digit span forward**, the examiner read out a sequence of numbers that the participant had to repeat in the same order. This task began with a set (i.e., two number sequences) consisting of two digits and increased to a set of nine digits. In **digit span backwards**, the examiner read out a sequence of numbers that the participant had to repeat in a reverse order. This task began with a set of two digits and increased to a set of eight digits. In **digit span sequencing**, the examiner read out a sequence of numbers that the participant had to sort in an ascending order. This task begins with a set of two digits and increased to a set of nine digits. Participants scored one point for each correctly repeated number sequence. The task was terminated if a participant failed to correctly repeat both number pairs of the same length (i.e., the same set).

Letter-number sequencing

Working memory was further tested with a **letter-number sequencing task** ('Cijfers & Letters', WAIS-IV-NL, Wechsler IV, 2012). The examiner first read out a randomized sequence of numbers and letters. The participant was required to repeat the sequence by first repeating the numbers in an ascending order and the letters in the alphabetic order (e.g., "S – 9 – T – 6" becomes "6 – 9 – S – T"). The task comprised a total of 30 number-letter sequences, divided into 10 sets, with three sequences in each set. The number of items in a sequence increased throughout the task, beginning with just two items (a letter and a number) and ending with a sequence consisting of eight items (four letters and four numbers). Participants scored one point for each correctly repeated letter-number sequence. The examiner stopped the task if a participant failed to correctly repeat all three pairs of letter-number sequences of the same length (i.e., the same set).

Non-word repetition

A shortened non-word repetition task (S-NWRT; Le Clercq et al., 2017) was used in the current study. The S-NWRT (Le Clerq et al., 2017) is a shortened version of the NWR task by Rispens and Baker (2012). The task contained 22 non-words. The non-words in the task were controlled for length (three to five syllables), phonotactic probability (10 non-words with a high and 12 non-words with a low phonotactic probability), and vowel type (both lax and tense vowels were used, and no consonant clusters). Participants heard an audio recording of each non-word once and were instructed to repeat the heard non-word as accurately as possible. Participants received one point for each non-word repeated with complete accuracy. The number of correctly repeated phonemes for each non-word was also counted and indicated by the percentage phoneme correct (PPC) score.

APPENDIX B

Materials for Chapters 2 & 3
(Gender and Number Disagreement Processing
with Event-Related Potentials)

The materials used in the two ERP experiments were the ones from Popov (2017). In the ERP listening experiment (Chapter 2), only trisyllabic experimental items (21-40) were used, while all experimental items (1-40) were used in the reading ERP experiment (Chapter 3). Filler items (1-20) remained the same across the two experiments.

Experimental Items (Chapter 2, N = 160; Chapter 3, N = 320)

1. Doek
Er is een wit doek in de bioscoop.
Hij heeft een enorm doek beschilderd.
De oude doeken beschermen de parketvloer tijdens het klussen.
De gedrapeerde doeken dienen ter decoratie.
Er is een witte doek in de bioscoop.
Hij heeft een enorme doek beschilderd.
Het oude doeken beschermen de parketvloer tijdens het klussen.
Het gedrapeerde doeken dienen ter decoratie.

2. Gas
Er is een giftig gas in de atmosfeer terecht gekomen.
Hij heeft een gevaarlijk gas ingeademd.
De schadelijke gassen zijn slecht voor het milieu.
De reukloze gassen zijn moeilijk waar te nemen.
Er is een giftig gas in de atmosfeer terecht gekomen.
Hij heeft een gevarlijke gas ingeademd.
Het schadelijke gassen zijn slecht voor het milieu.
Het reukloze gassen zijn moeilijk waar te nemen.

3. Fort
Hier stond een prachtig fort in de Middeleeuwen.
Zij heeft een indrukwekkend fort laten bouwen.
De grote forten staan verspreid over het landschap.
De oude forten werden vernield tijdens de oorlog.
Hier stond een prachtige fort in de Middeleeuwen.
Zij heeft een indrukwekkende fort laten bouwen.
Het grote forten staan verspreid over het landschap.
Het oude forten werden vernield tijdens de oorlog.

4. Hek
Hij heeft een lang hek laten verven.
Er stond een hoog hek om het landgoed.
De sierlijke hekken werden mooi verguld.
De stevige hekken werden snel gebouwd.
Hij heeft een lange hek laten verven.
Er stond een hoge hek om het landgoed.
Het sierlijke hekken werden mooi verguld.
Het stevige hekken werden snel gebouwd.

5. Front
Dat is een politiek front tegen windmolens.
Zij vormden een onverslaanbaar front tegen de vijand.
De radicale fronten vochten tegen elkaar.
De vijandelijke fronten zijn in gesprek.
Dat is een politieke front tegen windmolens.
Zij vormden een onverslaanbarefront tegen de vijand.
Het radicale fronten vochten tegen elkaar.
Het vijandelijke fronten zijn in gesprek.

6. Mes
Er lag een bloederig mes op de grond.
Zij legde een vlijmscherp mes op tafel.
De botte messen moeten geslepen worden.
De nieuwe messen snijden gemakkelijk.
Er lag een bloederige mes op de grond.
Zij legde een vlijmscherpe mes op tafel.
Het botte messen moeten geslepen worden.
Het nieuwe messen snijden gemakkelijk.

7. Nest
Er lag een kapot nest op de grond.
Zij bouwden een klein nest hoog in de boom.
De mooie nesten zijn vernield.
De lege nesten waren verspreid over het bos.
Er lag een kapotte nest op de grond.
Zij bouwden een kleine nest hoog in de boom.
Het mooie nesten zijn vernield.
Het lege nesten waren verspreid over het bos.

8. Net
Er hing een stevig net onder de trapeze.
Hij spande een klein net over de boomgaard.
De grote netten liggen in de zee.
De beschadigde netten werden gerepareerd.
Er hing een stevige net onder de trapeze.
Hij spande een kleine net over de boomgaard.
Het grote netten liggen in de zee.
Het beschadigde netten werden gerepareerd.

9. Oor
Er is eennieuw oor aan het kopje gelijmd.
Hij heeft een blauw oor door de kou.
De grote oren hielpen de wolf om beter te horen.
De gevoelige oren konden het harde geluid niet verdragen.
Er is een nieuwe oor aan het kopje gelijmd.
Hij heeft een blauwe oor door de kou.
Het grote oren hielpen de wolf om beter te horen.
Het gevoelige oren konden het harde geluid niet verdragen.

10. Park
Dat was een gevaarlijk park voor jonge kinderen.
Zij ontdekten een rustig park midden in de stad.
De mooie parken zijn druk op zomeravonden.
De groene parken moeten behouden blijven.
Dat was een gevaarlijke park voor jonge kinderen.
Zij ontdekten een rustige park midden in de stad.
Het mooie parken zijn druk op zomeravonden.
Het groene parken moeten behouden blijven.

11. Plein
Er was een groot plein voor de kerk.
Zij bezochten een prachtig plein in de oude stad.
De drukke pleinen zijn makkelijke doelwitten.
De kleine pleinen zijn met elkaar verbonden door steegjes.
Er was een grote plein voor de kerk.
Zij bezochten een prachtige plein in de oude stad.
Het drukke pleinen zijn makkelijke doelwitten.
Het kleine pleinen zijn met elkaar verbonden door steegjes.

12. Dorp
Er lag een mooi dorp vlakbij de grote stad.
Zij verliet een prachtig dorp met pijn in haar hart.
De gezellige dorpen trekken veel toeristen in de zomer.
De noordelijke dorpen hebben last van aardbevingen.
Er lag een mooie dorp vlakbij de grote stad.
Zij verliet een prachtige dorp met pijn in haar hart.
Het gezellige dorpen trekken veel toeristen in de zomer.
Het noordelijke dorpen hebben last van aardbevingen.

13. Touw
Er lag een kapot touw in de garage.
Hij bond een stevig touw om de mast.
De lange touwen hingen over de reling.
De dikke touwen waren om de paal geknoopt.
Er lag een kapotte touw in de garage.
Hij bond een stevige touw om de mast.
Het lange touwen hingen over de reling.
Het dikke touwen waren om de paal geknoopt.

14. Vak
Dat is een lastig vak volgens veel leerlingen.
Zij heeft een ander vak gekozen op school.
De moeilijke vakken werden het minst gewaardeerd.
De nieuwe vakken worden goed beoordeeld door studenten.
Dat is een lastige vak volgens veel leerlingen.
Zij heeft een andere vak gekozen op school.
Het moeilijke vakken werden het minst gewaardeerd.
Het nieuwe vakken worden goed beoordeeld door studenten.

15. Vlak
Er zat een vergeeld vlak op de muur.
Hij kleurde een groot vlak in met een stift.
De blauwe vlakken zijn opvallend.
De donkere vlakken moeten opnieuw worden geverfd.
Er zat een vergeelde vlak op de muur.
Hij kleurde een grote vlak in met een stift.
Het blauwe vlakken zijn opvallend.
Het donkere vlakken moeten opnieuw worden geverfd.

16. Wiel
Er zat een nieuw wiel op de fiets.
Zij verving een kapot wiel van de auto.
De kleine wielen reden over de weg.
De piepende wielen werden vervangen.
Er zat een nieuwe wiel op de fiets.
Zij verving een kapotte wiel van de auto.
Het kleine wielen reden over de weg.
Het piepende wielen werden vervangen.

17. Lint
Hier is een lang lint langs de weg gespannen.
Zij strikte een rood lint om haar vlecht.
De gekleurde linten hangen in de bomen.
De rafelige linten werden afgeknipt.
Hier is een lange lint langs de weg gespannen.
Zij strikte een rode lint om haar vlecht.
Het gekleurde linten hangen in de bomen.
Het rafelige linten werden afgeknipt.

18. Meer
Daar is een diep meer vol vissen.
Zij bezocht een rustig meer in de bossen.
De grote meren zijn echte trekpleisters voor toeristen.
De mooie meren worden het meest bezocht.
Daar is een diepe meer vol vissen.
Zij bezocht een rustige meer in de bossen.
Het grote meren zijn echte trekpleisters voor toeristen.
Het mooie meren worden het meest bezocht.

19. Pact
Dat was een historisch pact tussen Oost en West.
Zij sloten een geheim pact om dat bedrijf te saboteren.
De omvangrijke pacten zorgden voor veel problemen.
De belangrijke pacten veranderden de geschiedenis.
Dat was een historische pact tussen Oost en West.
Zij sloten een geheime pact om dat bedrijf te saboteren.
Het omvangrijke pacten zorgden voor veel problemen.
Het belangrijke pacten veranderden de geschiedenis.

20. Ras
Het is een nieuw ras van Nederlandse bodem.
Hij heeft een sterk ras gefokt.
De verschillende rassen reageren anders op prikkels.
De dure rassen zijn niet altijd beter.
Het is een nieuwe ras van Nederlandse bodem.
Hij heeft een sterke ras gefokt.
Het verschillende rassen reageren anders op prikkels.
Het dure rassen zijn niet altijd beter.

21. Apparaat
Er ligt een ongebruikt apparaat in de la.
Hij kocht een duur apparaat voor in de keuken.
De kleine apparaten zijn vaak even effectief als de grote.
De nieuwe apparaten zijn voorzien van technische snufjes.
Er ligt een ongebruikte apparaat in de la.
Hij kocht een dure apparaat voor in de keuken.
Het kleine apparaten zijn vaak even effectief als de grote.
Het nieuwe apparaten zijn voorzien van technische snufjes.

22. Avontuur
Dat was een spannend avontuur voor alle reisgenoten.
Hij beleeft een groot avontuur op safari.
De nieuwe avonturen worden beschreven in het boek.
De gevaarlijke avonturen zijn vaak het leukst.
Dat was een spannende avontuur voor alle reisgenoten.
Hij beleeft een grote avontuur op safari.
Het nieuwe avonturen worden beschreven in het boek.
Het gevaarlijke avonturen zijn vaak het leukst.

23. Compliment
Dat was een mooi compliment over haar werk.
Hij gaf een groot compliment aan zijn leerling.
De onverwachte complimenten zijn vaak het leukst.
De welgemeende complimenten werken motiverend.
Dat was een mooie compliment over haar werk.
Hij gaf een grote compliment aan zijn leerling.
Het onverwachte complimenten zijn vaak het leukst.
Het welgemeende complimenten werken motiverend.

24. Continent
Er ligt een enorm continent onder de evenaar.
Hij ontdekte een nieuw continent in de 15e eeuw.
De kleine continenten zijn goed vertegenwoordigd.
De indrukwekkende continenten werden door haar omschreven.
Er ligt een enorme continent onder de evenaar.
Hij ontdekte een nieuwe continent in de 15e eeuw.
Het kleine continenten zijn goed vertegenwoordigd.
Het indrukwekkende continenten werden door haar omschreven.

25. Document
Er is een oud document verdwenen uit het archief.
Zij leest een belangrijk document over klimaatverandering.
De uitgebreide documenten worden besproken.
De handige documenten zijn altijd binnen handbereik.
Er is een oude document verdwenen uit het archief.
Zij leest een belangrijke document over klimaatverandering.
Het uitgebreide documenten worden besproken.
Het handige documenten zijn altijd binnen handbereik.

26. Etiket
Hier is een groot etiket op geplakt.
Hij las een verkeerd etiket op de fles.
De mooie etiketten worden eerder verkocht.
De goedkope etiketten zien er minder goed uit.
Hier is een grote etiket op geplakt.
Hij las een verkeerde etiket op de fles.
Het mooie etiketten worden eerder verkocht.
Het goedkope etiketten zien er minder goed uit.

27. Formulier
Er ligt een belangrijk formulier in de kast.
Zij moest een lang formulier invullen voor school.
De medische formulieren moeten ingevuld worden.
De verplichte formulieren liggen op de stapel.
Er ligt een belangrijke formulier in de kast.
Zij moest een lange formulier invullen voor school.
Het medische formulieren moeten ingevuld worden.
Het verplichte formulieren liggen op de stapel.

28. Huwelijk
Dat was een vervelend huwelijk voor beide partijen.
Zij heeft een uitstekend huwelijk met haar echtgenoot.
De moderne huwelijken zijn anders dan vroeger.
De kerkelijke huwelijken zijn verbintenissen voor het leven.
Dat was een vervelende huwelijk voor beide partijen.
Zij heeft een uitstekende huwelijk met haar echtgenoot.
Het moderne huwelijken zijn anders dan vroeger.
Het kerkelijke huwelijken zijn verbintenissen voor het leven.

29. Incident
Dat was een ernstig incident tijdens de operatie.
Zij maakte een grappig incident mee in de kroeg.
De dagelijkse incidenten worden opgelost in een gesprek.
De recente incidenten worden besproken in de vergadering.
Dat was een ernstige incident tijdens de operatie.
Zij maakte een grappige incident mee in de kroeg.
Het dagelijkse incidenten worden opgelost in een gesprek.
Het recente incidenten worden besproken in de vergadering.

30. Instituut
Er is een officieel instituut voor statistiek.
Zij heeft een nieuw instituut voor vluchtelingenhulp opgericht.
De bekende instituten gaan anders te werk.
De christelijke instituten voor onderwijs werken samen.
Dat is een officiële instituut voor statistiek.
Zij heeft een nieuwe instituut voor vluchtelingenhulp opgericht.
Het bekende instituten gaan anders te werk.
Het christelijke instituten voor onderwijs werken samen.

31. Instrument
Er lag een zeldzaam instrument op het podium.
Hij gebruikte een klassiek instrument voor het concert.
De dure instrumenten zijn heel kwetsbaar.
De exotische instrumenten zijn moeilijk te bespelen.
Er lag een zeldzame instrument op het podium.
Hij gebruikte een klassieke instrument voor het concert.
Het dure instrumenten zijn heel kwetsbaar.
Het exotische instrumenten zijn moeilijk te bespelen.

32. Salaris
Er was een nieuw salaris vastgesteld voor die baan.
Hij verdiende een goed salaris met zijn baan.
De maandelijkse salarissen zijn op tijd uitbetaald.
De verlaagde salarissen zorgden voor veel onvrede.
Er was een nieuwe salaris vastgesteld voor die baan.
Hij verdiende een goede salaris met zijn baan.
Het maandelijkse salarissen zijn op tijd uitbetaald.
Het verlaagde salarissen zorgden voor veel onvrede.

33. Manuscript
Er lag een origineel manuscript van het boek in de kast.
Zij schreef een interessant manuscript over mode.
De afgekeurde manuscripten belandden bij het oud papier.
De complexe manuscripten waren te moeilijk voor de lezer.
Er lag een originele manuscript van het boek in de kast.
Zij schreef een interessante manuscript over mode.
Het afgekeurde manuscripten belandden bij het oud papier.
Het complexe manuscripten waren te moeilijk voor de lezer.

34. Monument
Het is een ontroerend monument geworden.
Hij bezocht een oud monument op de heuvel.
De moderne monumenten zijn zeker de moeite waard.
De beroemde monumenten bestaan al heel lang.
Het is een ontroerende monument geworden.
Hij bezocht een oude monument op de heuvel.
Het moderne monumenten zijn zeker de moeite waard.
Het beroemde monumenten bestaan al heel lang.

35. Pensioen
Het is een welverdiend pensioen voor deze werknemer.
U kunt een aanvullend pensioen opbouwen.
De verlaagde pensioenen zorgden voor veel onrust.
De nieuwe pensioenen zijn ongunstig voor veel werknemers.
Het is een welverdiende pensioen voor deze werknemer.
U kunt een aanvullende pensioen opbouwen.
Het verlaagde pensioenen zorgden voor veel onrust.
Het nieuwe pensioenen zijn ongunstig voor veel werknemers.

36. Ritueel
Er is een lang ritueel in het bos uitgevoerd.
Hij voerde een oud ritueel volgens traditie uit.
De heidense rituelen zijn onderdeel van de Halloweenviering.
De heilige rituelen zijn overbodig geworden.
Er is een lange ritueel in het bos uitgevoerd.
Hij voerde een oude ritueel volgens traditie uit.
Het heidense rituelen zijn onderdeel van de Halloweenviering.
Het heilige rituelen zijn overbodig geworden.

37. Resultaat
Er staat een onverwacht resultaat op de cijferlijst.
Zij kreeg een slecht resultaat terug.
De wekelijkse resultaten variëren altijd.
De teleurstellende resultaten zijn te wijten aan het onderwijs.
Er staat een onverwachte resultaat op de cijferlijst.
Zij kreeg een slechte resultaat terug.
Het wekelijkse resultaten variëren altijd.
Het teleurstellende resultaten zijn te wijten aan het onderwijs.

38. Schilderij
Er hing een goedkoop schilderij aan de muur.
Zij maakte een verrassend schilderij in de cursus.
De besmeurde schilderijen werden gerestaureerd.
De verkleurde schilderijen lagen op zolder.
Er hing een goedkope schilderij aan de muur.
Zij maakte een verrassende schilderij in de cursus.
Het besmeurde schilderijen werden gerestaureerd.
Het verkleurde schilderijen lagen op zolder.

39. Visioen
Dat was een helder visioen over de toekomst.
Hij kreeg een angstaanjagend visioen na het ongeluk.
De opmerkelijke visioenen zijn gebundeld in een boek.
De unieke visioenen worden uitgelegd.
Dat was een heldere visioen over de toekomst.
Hij kreeg een angstaanjagende visioen na het ongeluk.
Het opmerkelijke visioenen zijn gebundeld in een boek.
Het unieke visioenen worden uitgelegd.

40. Attribuut
Er is een nieuw attribuut in het assortiment.
Zij pakte een handig attribuut uit de keukenla.
De benodigde attributenliggen al klaar.
De geschikte attributen zijn hier te verkrijgen.
Er is een nieuwe attribuut in het assortiment.
Zij pakte een handige attribuut uit de keukenla.
Het benodigde attributen liggen al klaar.
Het geschikte attributen zijn hier te verkrijgen.

Fillers (N = 80)

1. Tomaat
Er ligt een rotte tomaat in de koelkast.
Zij heeft een rode tomaat van de plant geplukt.
Er ligt een rot tomaat in de koelkast.
Zij heeft een rood tomaat van de plant geplukt.

2. Crisis
Er ontstond een acute crisis bij het bedrijf.
Hij had een flinke crisis na het trauma.
Er ontstond een acuut crisis bij het bedrijf.
Hij had een flink crisis na het trauma.

3. Citroen
Er hangt een rijpe citroen aan de boom.
Zij kocht een zure citroen in de supermarkt.
Er hangt een rijp citroen aan de boom.
Zij kocht een zuur citroen in de supermarkt.

4. Balans
Er is een stevige balans nodig voor die oefening.
Ze maakte een nauwkeurige balans op voor het bedrijf.
Er is een stevig balans nodig voor die oefening.
Ze maakte een nauwkeurig balans op voor het bedrijf.

5. Viool
Er hing een zeldzame viool in de etalage.
Zij bespeelde een kostbare viool tijdens het concert.
Er hing een zeldzaam viool in de etalage.
Zij bespeelde een kostbaar viool tijdens het concert.

6. Tempel
Er staat een heilige tempel in de oude stad.
Ze bezochten een schitterende tempel op reis.
Er staat een heilig tempel in de oude stad.
Ze bezochten een schitterend tempel op reis.

7. Kliniek
Er is een uitstekende kliniek in die stad.
Hij bezit een beroemde kliniek voor drugsverslaafden.
Er is een uitstekend kliniek in die stad.
Hij bezit een beroemd kliniek voor drugsverslaafden.

8. Kopie
Hier ligt een geschikte kopie van de cijferlijst.
Zij maakte een duidelijke kopie van het testament.
Hier ligt een geschikt kopie van de cijferlijst.
Zij maakte een duidelijk kopie van het testament.

9. Impuls
Dat gaf een enorme impuls aan de ontwikkeling.
Zij wilde een grote impuls geven aan de kwaliteit van het onderwijs.
Dat gaf een enorme impuls aan de ontwikkeling.
Zij wilde een groot impuls geven aan de kwaliteit van het onderwijs.

10. Stoornis
Het is een ernstige stoornis die alleen voorkomt bij vrouwen.
Zij kreeg een milde stoornis in het spreken.
Het is een ernstig stoornis die alleen voorkomt bij vrouwen.
Zij kreeg een mild stoornis in het spreken.

11. Cursus
Er wordt een jaarlijkse cursus gegeven op school.
Zij verzorgt een intensieve cursus voor gepensioneerden.
Er wordt een jaarlijks cursus gegeven op school.
Zij verzorgt een intensief cursus voor gepensioneerden.

12. Status
Er is een bepaalde status die hij wil behalen.
Hij heeft een hoge status binnen de sector.
Er is een bepaald status die hij wil behalen.
Hij heeft een hoog status binnen de sector.

13. Woestijn
Er ligt een koude woestijn in Mongolië.
Zij bezoeken een hete woestijn tijdens de vakantie.
Er ligt een koud woestijn in Mongolië.
Zij bezoeken een heet woestijn tijdens de vakantie.

14. Sigaar
Er zat een kostbare sigaar in het doosje.
Hij stak een dure sigaar aan met de aansteker.
Er zat een kostbaar sigaar in het doosje.
Hij stak een duur sigaar aan met de aansteker.

15. Planeet
Dat is een onbekende planeet in ons zonnestelsel.
Hij tekende een grote planeet in het boek.
Dat is een onbekend planeet in ons zonnestelsel.
Hij tekende een groot planeet in het boek.

16. Fabriek
Er is een grote fabriek te vinden op het platteland.
Zij verbouwden een onveilige fabriek na veel protest.
Er is een groot fabriek te vinden op het platteland.
Zij verbouwden een onveilig fabriek na veel protest.

17. Ketting
Er ligt een unieke ketting bij de juwelier.
Hij gaf een dure ketting aan zijn vriendin.
Er ligt een uniek ketting bij de juwelier.
Hij gaf een duur ketting aan zijn vriendin.

18. Rivier
Daar stroomt een grote rivier door het landschap.
Zij staken een woeste rivier over op een vlot.
Daar stroomt een groot rivier door het landschap.
Zij staken een woest rivier over op een vlot.

19. Structuur
Het is een ingewikkelde structuur om uit te leggen.
Hij probeerde een simpele structuur te beschrijven.
Het is een ingewikkeld structuur om uit te leggen.
Hij probeerde een simpel structuur te beschrijven.

20. Factor
Dat is een onmisbare factor voor het proces.
Hij bezit een belangrijke factor om succesvol te worden.
Dat is een onmisbaar factor voor het proces.
Hij bezit een belangrijk factor om succesvol te worden.

Practice Items (N = 5)

Er is een uitstekende kliniek in die stad.
Hij probeerde een simpele structuur te beschrijven.
Daar stroomt een groot rivier door het landschap.
De zwakke signaal verbeterde langzaam.
Het noodzakelijke vetten staan op de dieetlijst.

APPENDIX C

Materials for Chapter 4 (Subject-Verb Disagreement Processing with Self-Paced Reading)

Experimental items (N = 192)

1. Delen
De man is erg opgelucht, omdat hij zijn zorgen deelt over zijn moeder.
De man is erg opgelucht, omdat hij zijn zorgen delen over zijn moeder.
De man is erg opgelucht, omdat hij bij zijn lieve vrouw zijn grote zorgen deelt over zijn moeder.
De man is erg opgelucht, omdat hij bij zijn lieve vrouw zijn grote zorgen delen over zijn moeder.

De jongens zijn erg boos, omdat ze een kamer delen met hun zusje.
De jongens zijn erg boos, omdat ze een kamer deelt met hun zusje.
De jongens zijn erg boos, omdat ze bij elke vakantie een hele kleine kamer delen met hun zusje.
De jongens zijn erg boos, omdat ze bij elke vakantie een hele kleine kamer deelt met hun zusje.

De mannen zorgen voor ophef, omdat ze een bericht delen van de president.
De mannen zorgen voor ophef, omdat ze een bericht deelt van de president.
De mannen zorgen voor veel ophef, omdat ze op alle sociale media een omstreden bericht delen van de president.
De mannen zorgen voor veel ophef, omdat ze op alle sociale media een omstreden bericht deelt van de president.

2. Kussen
De jongen is erg blij, omdat hij zijn ouders kusst na zijn operatie.
De jongen is erg blij, omdat hij zijn ouders kussen na zijn operatie.
De jongen is erg blij, omdat hij in het ziekenhuis zijn ontzettend bezorge ouders kusst na zijn operatie.
De jongen is erg blij, omdat hij in het ziekenhuis zijn ontzettend bezorgde ouders kussen na zijn operatie.

De man is heel gelukkig, omdat hij voor de eerste keer zijn nieuwe vrouw kust tijdens de bruiloft.
De man is heel gelukkig, omdat hij voor de eerste keer zijn nieuwe vrouw kussen tijdens hun bruiloft.
De man is heel gelukkig, omdat hij zijn vrouw kust tijdens hun bruiloft.
De man is heel gelukkig, omdat hij zijn vrouw kussen tijdens hun bruiloft.

3. Haten
De jongen zit in therapie, omdat hij zijn ouders haat door zijn depressie.
De jongen zit in therapie, omdat hij zijn ouders haten door zijn depressie.
De jongen zit in therapie, omdat hij op dit moment zijn heel bezorgde ouders haat door zijn depressie.
De jongen zit in therapie, omdat hij op dit moment zijn heel bezorgde ouders haten door zijn depressie.
De jongen is erg verdrietig, omdat hij zijn huis haat na de verhuizing.
De jongen is erg verdrietig, omdat hij zijn huis haten na de verhuizing.
De jongen is erg verdrietig, omdat hij ondanks alle verwachtingen zijn net gekochte huis haat na de verhuizing.
De jongen is erg verdrietig, omdat hij ondanks alle verwachtingen zijn net gekochte huis haten na de verhuizing.

De mannen zijn erg ongelukkig, omdat ze hun baan haten ondanks leuke collega's.
De mannen zijn erg ongelukkig, omdat ze hun baan haat ondanks leuke collega's.
De mannen zijn erg ongelukkig, omdat ze sinds het begin hun ontzettend saaie baan haten ondanks leuke collega's.
De mannen zijn erg ongelukkig, omdat ze sinds het begin hun ontzettend saaie baan haat ondanks leuke collega's.

4. Leiden
De jongen is goed bezig, omdat hij de groepen leidt met de begeleider.
De jongen is goed bezig, omdat hij de groepen leiden met de begeleider.
De jongen is goed bezig, omdat hij voor het bedrijf de grote nieuwe groepen leidt met de begeleider.
De jongen is goed bezig, omdat hij voor het grote bedrijf grote nieuwe groepen leiden met de begeleider.

De jongen is heel trots, omdat hij het orkest leidt met zijn vriendin.
De jongen is heel trots, omdat hij het orkest leiden met zijn vriendin.
De jongen is heel trots, omdat hij binnen de noordelijke gemeenten het grootste orkest leidt met zijn vriendin.
De jongen is heel trots, omdat hij binnen de noordelijke gemeenten het grootste orkest leiden met zijn vriendin.

5. Dienen
De lakei voelt zich nuttig, omdat hij de prinsen dient in het paleis.
De lakei voelt zich nuttig, omdat hij de prinsen dienen in het paleis.
De lakei voelt zich nuttig, omdat hij op een degelijke manier de jonge prinsen dient in het paleis.
De lakei voelt zich nuttig, omdat hij op een degelijke manier de jonge prinsen dienen in het paleis.

De jongen vindt het spannend, omdat hij zijn land dient in de oorlog.
De jongen vindt het spannend, omdat hij zijn land dienen in de oorlog.
De jongen vindt het spannend, omdat hij zonder de juiste voorbereiding zijn enige land dient in de oorlog.
De jongen vindt het spannend, omdat hij zonder de juiste voorbereiding zijn enige land dienen in de oorlog.

6. Vangen
De politieman is erg opgelucht, omdat hij de bendes vangt in een achtervolging.
De politieman is erg opgelucht, omdat hij de bendes vangen in een achtervolging.
De politieman is erg opgelucht, omdat hij met zijn ervaren collega's de ontsnapte bendes vangt in een achtervolging.
De politieman is erg opgelucht, omdat hij met zijn ervaren collega's de ontsnapte bendes vangen in een achtervolging.

De keeper juicht van vreugde, omdat hij de voetbal vangt in het doel.
De keeper juicht van vreugde, omdat hij de voetbal vangen in het doel.
De keeper juicht van vreugde, omdat hij tijdens een zeer spannende wedstrijd de voetbal vangt in het doel.
De keeper juicht van vreugde, omdat hij tijdens een zeer spannende wedstrijd de voetbal vangen in het doel.

De eilandbewoners zijn erg blij, omdat ze eiwitrijke vissen vangen met hun hengel.
De eilandbewoners zijn erg blij, omdat ze eiwitrijke vissen vangt met hun hengel.
De eilandbewoners zijn erg blij, omdat ze in de grote zee hele eiwitrijke vissen vangen met hun hengel.
De eilandbewoners zijn erg blij, omdat ze in de grote zee hele eiwitrijke vissen vangt met hun hengel.

De accountants zijn erg tevreden, omdat ze veel geld vangen voor hun werkzaamheden.

De accountants zijn erg tevreden, omdat ze veel geld vangt voor hun werkzaamheden.
De accountants zijn erg tevreden, omdat ze met hun ervaren compagnons erg veel geld vangen voor hun werkzaamheden.
De accountants zijn erg tevreden, omdat ze met hun ervaren compagnons erg veel geld vangt voor hun werkzaamheden.

7. Bouwen
De jongen zit in de weg, omdat hij twee torens bouwt op de grond.
De jongen zit in de weg, omdat hij twee torens bouwen op de grond.
De jongen zit in de weg, omdat hij van houten blokken twee hele hoge torens bouwt op de grond.
De jongen zit in de weg, omdat hij van houten blokken twee hele hoge torens bouwen op de grond.

De metselaar maakt het cement, omdat hij een muur bouwt bij de buren.
De metselaar maakt het cement, omdat hij een muur bouwen bij de buren.
De metselaar maakt het cement, omdat hij om de tuin een hele hoge muur bouwt bij de buren.
De metselaar maakt het cement, omdat hij om de tuin een hele hoge muur bouwen bij de buren.
De mannen zijn in Groningen, omdat ze hun huis bouwen op gemeentelijke grond.
De mannen zijn in Groningen, omdat ze hun huis bouwt op gemeentelijke grond.
De mannen zijn in Groningen, omdat ze in de stad hun eerste eigen huis bouwen op gemeentelijke grond.
De mannen zijn in Groningen, omdat ze in de stad hun eerste eigen huis bouwt op gemeentelijke grond.

8. Duwen
De man is buiten adem, omdat hij de auto’s duwt met zijn vader.
De man is buiten adem, omdat hij de auto’s duwen met zijn vader.
De man is buiten adem, omdat hij in de hoge bergen de kapotte auto’s duwt met zijn vader.
De man is buiten adem, omdat hij in de hoge bergen de kapotte auto’s duwen met zijn vader.

De jongens voelen zich schuldig, omdat ze de meiden duwen tijdens het spelen.
De jongens voelen zich schuldig, omdat ze de meiden duwt tijdens het spelen.
De jongens voelen zich schuldig, omdat ze in de speeltuin de twee jonge meiden duwen tijdens het spelen.
De jongens voelen zich schuldig, omdat ze in de speeltuin de twee mooie jonge meiden duwt tijdens het spelen.

9. Voeren
Mijn neefje is erg blij, omdat hij de eendjes voert in het park.
Mijn neefje is erg blij, omdat hij de eendjes voeren in het park.
Mijn neefje is erg blij, omdat hij met zijn lieve moeder de kleine eendjes voert in het park.
Mijn neefje is erg blij, omdat hij met zijn lieve moeder de kleine eendjes voeren in het park.

De verpleger voelt zich nederig, omdat hij de mannen voert in het ziekenhuisbed.
De verpleger voelt zich nederig, omdat hij de mannen voeren in het ziekenhuisbed.
De verpleger voelt zich nederig, omdat hij met veel peersonlijk offer de zieke mannen voert in het ziekenhuisbed.
De verpleger voelt zich nederig, omdat hij met veel peersonlijk offer de zieke mannen voeren in het ziekenhuisbed.

De baas is erg gespannen, omdat hij een gesprek voert met zijn werknemers.
De baas is erg gespannen, omdat hij een gesprek voeren met zijn werknemers.
De baas is erg gespannen, omdat hij met heel veel tegenzin een moeilijk gesprek voert met zijn werknemer.
De baas is erg gespannen, omdat hij met heel veel tegenzin een moeilijk gesprek voeren met zijn werknemer.

De soldaten voelen zich bedreigd, omdat ze een oorlog voeren met sterke tegenstanders.
De soldaten voelen zich bedreigd, omdat ze een oorlog voert met sterke tegenstanders.
De soldaten voelen zich bedreigd, omdat ze in het zwakke leger een gevaarlijke oorlog voeren met een sterke tegenstander.
De soldaten voelen zich bedreigd, omdat ze in het zwakke leger een gevaarlijke oorlog voert met een sterke tegenstander.

10. Tonen
De man krijgt veel lof, omdat hij heldhaftige daden toont in het leger.
De man krijgt veel lof, omdat hij heldhaftige daden tonen in het leger.
De man krijgt heel veel lof, omdat hij op geheel onverschrokken wijze zijn heldhaftige daden toont in het leger.
De man krijgt heel veel lof, omdat hij op geheel onverschrokken wijze zijn heldhaftige daden tonen in het leger.

De buren voelen zich nostalgisch, omdat ze oude foto's tonen aan hun kleinkinderen.
De buren voelen zich nostalgisch, omdat ze oude foto's toont aan hun kleinkinderen.
De buren voelen zich nostalgisch, omdat ze op vakantie een hele stapel oude foto's tonen aan hun kleinkinderen.
De buren voelen zich nostalgisch, omdat ze op vakantie een hele stapel oude foto's toont aan hun kleinkinderen.

De mannen zijn erg sympathiek, omdat ze veel liefde tonen aan hun medemensen.
De mannen zijn erg sympathiek, omdat ze veel liefde toont aan hun medemensen.
De mannen zijn erg sympathiek, omdat ze zonder enkele moeite heel veel echte liefde tonen aan hun medemensen.
De mannen zijn erg sympathiek, omdat ze zonder enkele moeite heel veel echte liefde toont aan hun medemensen.

De jongen is erg kwetsbaar, omdat hij zijn angst toont bij zijn vrienden.
De jongen is erg kwetsbaar, omdat hij zijn angst tonen bij zijn vrienden.
De jongen is erg kwetsbaar, omdat hij voor de eerste keer zijn verborgen angst toont bij zijn vrienden.
De jongen is erg kwetsbaar, omdat hij voor de eerste keer zijn verborgen angst tonen bij zijn vrienden.

11. Vieren
De man is erg blij, omdat hij de deal viert met zijn werknemers.
De man is erg blij, omdat hij de deal vieren met zijn werknemers.
De man is erg blij, omdat hij bij zijn nieuwe werk de winstgevende deal viert met zijn werknemers.
De man is erg blij, omdat hij bij zijn nieuwe werk de winstgevende deal vieren met zijn werknemers.
De mannen voelen zich euforisch, omdat ze meerdere feesten vieren voor hun verjaardagen.
De mannen voelen zich euforisch, omdat ze meerdere feesten viert voor hun verjaardagen.
De mannen voelen zich euforisch, omdat ze binnen hun hechte vriendengroep meerdere grote feesten vieren voor hun verjaardagen.
De mannen voelen zich euforisch, omdat ze binnen hun hechte vriendengroep meerdere grote feesten viert voor hun verjaardagen.

12. Roken
Mijn opa hoest heel vaak, omdat hij een pijp rookt in de woonkamer.
Mijn opa hoest heel vaak, omdat hij een pijp roken in de woonkamer.
Mijn opa hoest heel vaak, omdat hij bijna elke dag een grote oude pijp rookt in de woonkamer.
Mijn opa hoest heel vaak, omdat hij bijna elke dag een grote oude pijp roken in de woonkamer.

De visboeren zijn erg trots, omdat ze hun visjes roken in de achtertuin.
De visboeren zijn erg trots, omdat ze hun visjes rookt in de achtertuin.
De visboeren zijn erg trots, omdat ze op ambachtelijke wijze hun vers gevangen visjes roken in de achtertuin.
De visboeren zijn erg trots, omdat ze op ambachtelijke wijze hun vers gevangen visjes rookt in de achtertuin.

De managers zijn erg geliefd, omdat ze een sigaar roken met hun collega's.
De managers zijn erg geliefd, omdat ze een sigaar rookt met hun collega's.
De managers zijn erg geliefd, omdat ze tijdens elke pauze een grote dikke sigaar roken met hun collega's.
De managers zijn erg geliefd, omdat ze tijdens elke pauze een grote dikke sigaar rookt met hun collega's.

13. Lenen
De man is heel dankbaar, omdat hij veel geld leent van zijn broer.
De man is heel dankbaar, omdat hij veel geld lenen van zijn broer.
De man is heel dankbaar, omdat hij voor de tweede keer heel veel geld leent van zijn broer.
De man is heel dankbaar, omdat hij voor de tweede keer heel veel geld lenen van zijn broer.

14. Zingen
De jongen is heel nerveus, omdat hij een nummer zingt tijdens de talentenjacht.
De jongen is heel nerveus, omdat hij een nummer zingen tijdens de talentenjacht.
De jongen is heel nerveus, omdat hij van een onbekende band een nieuw nummer zingt tijdens de talentenjacht.
De jongen is heel nerveus, omdat hij van een onbekende band een nieuw nummer zingen tijdens de talentenjacht.

De jongens voelen zich ongemakkelijk, omdat ze de liedjes zingen in de kroeg.
De jongens voelen zich ongemakkelijk, omdat ze de liedjes zingt in de kroeg.

De jongens voelen zich ongemakkelijk, omdat ze voor een groot publiek de populaire liedjes zingen in de kroeg.
De jongens voelen zich ongemakkelijk, omdat ze voor een groot publiek de populaire liedjes zingt in de kroeg.

15. Pikken
De haan wordt erg dik, omdat hij veel granen pikt van de grond.
De haan wordt erg dik, omdat hij veel granen pikken van de grond.
De haan wordt erg dik, omdat hij bij elke hap veel grote gemengde granen pikt van de grond.
De haan wordt erg dik, omdat hij bij elke hap veel grote gemengde granen pikken van de grond.

Het jongetje doet erg voorzichtig, omdat hij twee koeken pikt uit de koektrommel.
Het jongetje doet erg voorzichtig, omdat hij twee koeken pikken uit de koektrommel.
Het jongetje doet erg voorzichtig, omdat hij, zonder het te vragen, twee grote koeken pikt uit de koektrommel.
Het jongetje doet erg voorzichtig, omdat hij, zonder het te vragen, twee grote koeken pikken uit de koektrommel.

De jongens rennen hard weg, omdat ze wat dvd's pikken uit de winkel.
De jongens rennen hard weg, omdat ze wat dvd's pikt uit de winkel.
De jongens rennen hard weg, omdat ze van de bekende film wat nieuwe dvd's pikken uit de winkel.
De jongens rennen hard weg, omdat ze van de bekende film wat nieuwe dvd's pikt uit de winkel.

De jongens zijn ontzettend sluw, omdat ze het idee pikken van andere mensen.
De jongens zijn ontzettend sluw, omdat ze het idee pikt van andere mensen.
De jongens zijn ontzettend sluw, omdat ze voor een groot project het geweldige idee pikken van andere mensen.
De jongens zijn ontzettend sluw, omdat ze voor een groot project het geweldige idee pikt van andere mensen.

16. Huren
De studenten kopen geen fiets, omdat ze hun fietsen huuren voor een jaartje.
De studenten kopen geen fiets, omdat ze hun fietsen huurt voor een jaartje.
De studenten kopen geen fiets, omdat ze voor weinig geld hun mooie nieuwe fietsen huuren voor een jaartje.

De studenten kopen geen fiets, omdat ze voor weinig geld hun mooie nieuwe fietsen huurt voor een jaartje.

De jongens rijden erg voorzichtig, omdat ze een wagen huren voor de verhuizing.
De jongens rijden erg voorzichtig, omdat ze een wagen huurt voor de verhuizing.
De jongens rijden erg voorzichtig, omdat ze van hun lieve opa een dure wagen huren voor de verhuizing.
De jongens rijden erg voorzichtig, omdat ze van hun lieve opa een dure wagen hurt voor de verhuizing.

17. Tellen
De jongens voelen zich verantwoordelijk, omdat ze de stemmen tellen in de verkiezingen.
De jongens voelen zich verantwoordelijk, omdat ze de stemmen telt in de verkiezingen.
De jongens voelen zich verantwoordelijk, omdat ze voor de eerste keer de lokale stemmen tellen in de verkiezingen.
De jongens voelen zich verantwoordelijk, omdat ze voor de eerste keer de lokale stemmen telt in de verkiezingen.

De herder voelt zich nuttig, omdat hij zijn kudde telt in het weiland.
De herder voelt zich nuttig, omdat hij zijn kudde tellen in het weiland.
De herder voelt zich nuttig, omdat hij in de vroege ochtend zijn grote kudde telt in het weiland.
De herder voelt zich nuttig, omdat hij in de vroege morgen zijn grote kudde tellen in het weiland.

18. Bakken
De chefs hebben het druk, omdat ze steenoven pizza’s bakken volgens origineel recept.
De chefs hebben het druk, omdat ze steenoven pizza’s bakt volgens origineel recept.
De chefs hebben het druk, omdat ze op dit moment meerdere verrukkelijke steenoven pizza’s bakken volgens origineel recept.
De chefs hebben het druk, omdat ze op dit moment meerdere verrukkelijke steenoven pizza’s bakt volgens origineel recept.

De mannen zijn in de keuken, omdat ze een taart bakken in de oven.
De mannen zijn in de keuken, omdat ze een taart bakt in de oven.
De mannen zijn in de keuken, omdat ze voor de eerste keer een heerlijke taart bakken in de oven.
De mannen zijn in de keuken, omdat ze voor de eerste keer een heerlijke taart bakt in de oven.

19. Raden
De jongens winnen de quiz, omdat ze het liedje raden in de kroeg.
De jongens winnen de quiz, omdat ze het liedje raadt in de kroeg.
De jongens winnen de quiz, omdat ze onder grote tijdsdruk het laatst afgespeelde liedje raden in de kroeg.
De jongens winnen de quiz, omdat ze onder grote tijdsdruk het laatst afgespeelde liedje raden in de kroeg.

Fillers (N = 64; all fillers are from the study by Dragoy et al., 2011)

Grammatical:

Deze mening werdt door vele anderen gedeeld.
De witte tanden werden door het kind gepoetst.
Hij hoopte dat hij doorkreeg waardoor het kwam.
Italianen drinken noot recht uit de fles maar altijd uit een glas.
Op het schoolbord staat een mooi gedicht geschreven.
De huisvrouwen zullen het blik bonen openen.
De agenten schreven een flinke bon uit.
Hopelijk maakt je verloogde zich niet al teveel zorgen.
De brutale misdadige overtraden de wet.
Het kleine boompje werd geplant toen ik werd geboren.
Het gekreukte overhemd werd door de werkster gestreken.
De zilveren dwarsfluit werd door het orkestlid bespeeld.
Het bruine brood werd elke dag vers gebakken.
Het wollen truitje werd door mijn grootmoeder gebreid.
Het grote zeil werd al snel gehesen door de matrozen.
De jonkheren aten dagelijks een gekookt eitje.
Het milieu is sterk vervuild door alle vieze fabrieken.
Over de weg rende een kudde schapen terwijl hij haast had.
De zakelijke brief werd door de secretaresses getypt.
Deze sinaasappels geven niet zoveel sap.
De priesters steken een witten kaars aan.
De trap omhoog is mij veel te stijl.
Deze Nederlander heeft duidelijk geen smaak.
Het koren werd door de forse molenaars gemalen.
Het hele gezin speelde het nieuwe bordspel tot laat in de avond.
De uitzending wordt door een vrij jong publiek bekeken.
Het hardnekkige onkruid groeit overal, tussen de stenen door.
De kleuters maakten een grote witte sneeuwpop.
Het klinkt leuker dan het is omdat je er niet bij bent.

De ronde pil werd door de verslaafde geslikt zonder dat iemand het merkte.
Het correcte antwoord kreeg ik van de leraren.
De kamermeisjes maken samen het grote bed op voordat de president kwam.

Ungrammatical:

Deze mening werden door vele anderen gedeeld.
De witte tanden werdt door het kind gepoetst.
Hij hoopten dat hij doorkreeg waardoor het kwam.
Italianen drinkt noot recht uit de fles maar altijd uit een glas.
Op het schoolbord staan een mooi gedicht geschreven.
De huisvrouwen zal het blik bonen openen.
De agenten schreef een flinke bon uit.
Hopelijk maken je verloogde zich niet al teveel zorgen.
De brutale misdadige overtradt de wet.
Het kleine boompje werden geplant toen ik werd geboren.
Het gekreukte overhemd werden door de werkster gestreken.
De zilveren dwarsfluit werden door het orkestlid bespeeld.
Het bruine brood werden elke dag vers gebakken.
Het wollen truitje werden door mijn grootmoeder gebreid.
Het grote zeil werden al snel gehesen door de matrozen.
De jonkheren at dagelijks een gekookt eitje.
Het milieu zijn sterk vervuild door alle vieze fabrieken.
Over de weg renden een kudde schapen terwijl hij haast had.
De zakelijke brief werden door de secretaresses getypt.
Deze sinaasappels geeft niet zoveel sap.
De priesters steek een witten kaars aan.
De trap omhoog zijn mij veel te stijl.
Deze Nederlander hebt duidelijk geen smaak.
Het koren werden door de forse molenaars gemalen.
Het hele gezin speelden het nieuwe bordspel tot laat in de avond.
De uitzending worden door een vrij jong publiek bekeken.
Het hardnekkige onkruid groeien overal, tussen de stenen door.
De kleuters maakte een grote witte sneeuwpop.
Het klinkt leuker dan het zijn omdat je er niet bij bent.
De ronde pil werden door de verslaafde geslikt zonder dat iemand het merkte.
Het correcte antwoord kregen ik van de leraren.
De kamermeisjes maakt samen het grote bed op voordat de president kwam.

Practice Items (N = 5)

De mannen krijgen een bekeuring, omdat ze de spelers roepen na de wedstrijd.

De zwerver is ontzettend geliefd, omdat hij naar de voorbijgaande mensen veel vriendelijke dingen roepen vanaf de stoep.

De jongen mist een pakketje, omdat hij een soep koken in de keuken.

Die meisjes die buiten spelen houden van chocolade.

De mannen hebben het druk, omdat ze voor de hele familie twee verschillende pasta's koken na het werken.

APPENDIX D

Tables with the ANOVA results from Chapter 2

D

Table D.1 Results of repeated measures ANOVAs for the gender condition in Chapter 2 (ERP listening experiment on adults with dyslexia).

Time window	100-300	300-500	500-700	700-900	900-1100	1100-1300	1300-1500
		Lateral regions					
Grammaticality	$F(12) = 0.306$, $p = .59$, $\eta^2 = 0.025$	$F(12) = 0.078$, $p = .785$, $\eta^2 = 0.006$	$F(12) = 0.052$, $p = .823$, $\eta^2 = 0.004$	$F(12) = 0.085$, $p = .775$, $\eta^2 = 0.007$	$F(12) = 0.327$, $p = .578$, $\eta^2 = 0.027$	$F(12) = 0.109$, $p = .747$, $\eta^2 = 0.009$	$F(12) = 0.079$, $p = .784$, $\eta^2 = 0.007$
Grammaticality x Anteriority	$F(12) = 0.006$, $p = .954$, $\eta^2 = 0.000$	$F(12) = 0.226$, $p = .688$, $\eta^2 = 0.018$	$F(12) = 0.141$, $p = .736$, $\eta^2 = 0.012$	$F(12) = 2.847$, $p = .115$, $\eta^2 = 0.192$	$F(12) = 0.462$, $p = .519$, $\eta^2 = 0.037$	$F(12) = 0.044$, $p = .855$, $\eta^2 = 0.004$	$F(12) = 0.014$, $p = .924$, $\eta^2 = 0.001$
Grammaticality x Hemisphere	$F(12) = 0.085$, $p = .775$, $\eta^2 = 0.007$	$F(12) = 0.091$, $p = .768$, $\eta^2 = 0.008$	$F(12) = 0.07$, $p = .796$, $\eta^2 = 0.006$	$F(12) = 0.208$, $p = .656$, $\eta^2 = 0.017$	$F(12) = 0.753$, $p = .402$, $\eta^2 = 0.059$	$F(12) = 1.173$, $p = .3$, $\eta^2 = 0.089$	$F(12) = 0.293$, $p = .598$, $\eta^2 = 0.024$
Grammaticality x Hemisphere x Anteriority	$F(12) = 1.771$, $p = .207$, $\eta^2 = 0.129$	$F(12) = 2.762$, $p = .117$, $\eta^2 = 0.187$	$F(12) = 1.937$, $p = .188$, $\eta^2 = 0.139$	$F(12) = 1.81$, $p = .202$, $\eta^2 = 0.131$	$F(12) = 1.77$, $p = .207$, $\eta^2 = 0.129$	$F(12) = 1.09$, $p = .326$, $\eta^2 = 0.083$	$F(12) = 1.460$, $p = .251$, $\eta^2 = 0.108$
		Midline regions					
Grammaticality	$F(12) =0.005$, $p = .947$, $\eta^2 = 0.000$	$F(12) = 0.471$, $p = .506$, $\eta^2 = 0.038$	$F(12) = 0.014$, $p = .909$, $\eta^2 = 0.001$	$F(12) = 0.004$, $p = .952$, $\eta^2 = 0.000$	$F(12) = 0.122$, $p = .733$, $\eta^2 = 0.010$	$F(12) = 0.141$, $p = .714$, $\eta^2 = 0.012$	$F(12) = 0.029$, $p = .868$, $\eta^2 = 0.002$
Grammaticality x Anteriority	$F(12) = 0.044$, $p = .868$, $\eta^2 = 0.004$	$F(12) = 0.475$, $p = .547$, $\eta^2 = 0.038$	$F(12) = 0.229$, $p = .676$, $\eta^2 = 0.019$	$F(12) = 3.086$, $p = .101$, $\eta^2 = 0.205$	$F(12) = 0.912$, $p = .336$, $\eta^2 = 0.071$	$F(12) = 0.288$, $p = .614$, $\eta^2 = 0.023$	$F(12) = 0.107$, $p = .759$, $\eta^2 = 0.009$

Note: The top part of the table shows the results for the ANOVAs with the lateral regions of interest and had grammaticality (2 levels: grammatical and ungrammatical), hemisphere (2 levels: left and right hemisphere), and anteriority (3 levels: anterior, central, and posterior) as within-subject factors. The second part of the table shows the repeated measures ANOVAs that only looked at the regions of interest in the midline regions and had grammaticality (2 levels: grammatical and ungrammatical), and anteriority (3 levels: anterior, central, and posterior) as between-subject factors. As an effect size statistic for the ANOVA analyses, we report partial eta squared (η^2).

Table D.2 Results of repeated measures ANOVAs for the number condition in Chapter 2 (ERP listening experiment on adults with dyslexia).

Time window	100-300	300-500	500-700	700-900	900-1100	1100-1300	1300-1500
		Lateral regions					
Grammaticality	$F(12) = 0.169$, $p = .688$, $\eta^2 = .014$	$F(12) = 0.32$, $p = .582$, $\eta^2 = .026$	$F(12) = 0.52$, $p = .485$, $\eta^2 = .042$	$F(12) = 3.684$, $p = .079$, $\eta^2 = .235$.	$F(12) = 1.902$, $p = .193$, $\eta^2 = .137$	$F(12) = 3.105$, $p = .103$, $\eta^2 = .206$	$F(12) = 0.458$, $p = .511$, $\eta^2 = .037$
Grammaticality x Anteriority	$F(12) = 0.129$, $p = .768$, $\eta^2 = .011$	$F(12) = 1.376$, $p = .268$, $\eta^2 = .103$	$F(12) = 0.686$, $p = .447$, $\eta^2 = .054$	$F(12) = 8.601$, $p = .004$, $\eta^2 = .418$	$F(12) = 1.297$, $p = .285$, $\eta^2 = .098$	$F(12) = 6.392$, $p = .013$, $\eta^2 = .348$	$F(12) = 0.02$, $p = .919$, $\eta^2 = .002$
Grammaticality x Hemisphere	$F(12) = 0.061$, $p = .809$, $\eta^2 = .005$	$F(12) = 13.504$, $p = .003$, $\eta^2 = .529$	$F(12) = 5.263$, $p = .041$, $\eta^2 = .305$	$F(12) = 0.496$, $p = .495$, $\eta^2 = .04$	$F(12) = 0.472$, $p = .505$, $\eta^2 = .038$	$F(12) = 0.533$, $p = .479$, $\eta^2 = .043$	$F(12) = 3.779$, $p = .076$, $\eta^2 = .24$
Grammaticality x Hemisphere x Anteriority	$F(12) = 0.172$, $p = .686$, $\eta^2 = .014$	$F(12) = 1.507$, $p = .246$, $\eta^2 = .112$	$F(12) = 1.422$, $p = .262$, $\eta^2 = .106$	$F(12) = 0.192$, $p = .719$, $\eta^2 = .016$	$F(12) = 0.184$, $p = .706$, $\eta^2 = .015$	$F(12) = 0.406$, $p = .572$, $\eta^2 = .033$	$F(12) = 0.807$, $p = .398$, $\eta^2 = .063$
		Midline regions					
Grammaticality	$F(12) = 0.693$, $p = .421$, $\eta^2 = .055$	$F(12) = 0.35$, $p = .565$, $\eta^2 = .028$	$F(12) = 0.606$, $p = .451$, $\eta^2 = .048$	$F(12) = 5.264$, $p = .041$, $\eta^2 = .305$	$F(12) = 2.384$, $p = .149$, $\eta^2 = .166$	$F(12) = 2.736$, $p = .124$, $\eta^2 = .186$	$F(12) = 0.538$, $p = .477$, $\eta^2 = .043$
Grammaticality x Anteriority	$F(12) =0.336$, $p = .655$, $\eta^2 = .027$	$F(12) = 0.953$, $p = .363$, $\eta^2 = .074$	$F(12) = 0.673$, $p = .443$, $\eta^2 = .053$	$F(12) = 9.073$, $p = .006$, $\eta^2 = .431$	$F(12) = 2.018$, $p = .175$, $\eta^2 = .144$	$F(12) = 8.374$, $p = .008$, $\eta^2 = .411$	$F(12) = 0.985$, $p = .348$, $\eta^2 = .076$

Note: The top part of the table shows the results for the ANOVAs with the lateral regions of interest and had grammaticality (2 levels: grammatical and ungrammatical), hemisphere (2 levels: left and right hemisphere), and anteriority (3 levels: anterior, central, and posterior) as between-subject factors. The second part of the table shows the repeated measures ANOVAs that only looked at the regions of interest in the midline regions and had grammaticality (2 levels: grammatical and ungrammatical), and anteriority (3 levels: anterior, central, and posterior) as within-subject factors. As an effect size statistic for the ANOVA analyses, we report partial eta squared (η^2).

APPENDIX E

Table with the ANOVA results from Chapter 3

Table E.1. Results of repeated measures ANOVAs for Chapter 3 (ERP reading experiment on adults with dyslexia).

Time window	300-450	450-600	600-800	800-1000
		Lateral regions		
Grammaticality	$F(22) = 0.35$, $p = .56$, $\eta^2 = .016$	$F(22) = 4.196$, $p = .053$, $\eta^2 = .160$	$F(22) = 1.636$, $p = .214$, $\eta^2 = .069$	$F(22) = 0.812$, $p = .377$, $\eta^2 = .036$
Grammaticality x Anteriority	$F(22) = 2.506$, $p = .116$, $\eta^2 = .102$	$F(22) = 0.612$, $p = .469$, $\eta^2 = .027$	$F(22) = 0.359$, $p = .614$, $\eta^2 = .016$	$F(22) = 11.269$, $p = .001$, $\eta^2 = .339$
Grammaticality x Hemisphere	$F(22) = 1.342$, $p = .259$, $\eta^2 = .058$	$F(22) = 0.232$, $p = .635$, $\eta^2 = .010$	$F(22) = 1.236$, $p = .278$, $\eta^2 = .053$	$F(22) = 1.836$, $p = .189$, $\eta^2 = .077$
Grammaticality x Condition	$F(22) = 0.638$, $p = .433$, $\eta^2 = .028$	$F(22) = 0.039$, $p = .846$, $\eta^2 = .002$	$F(22) = 0.831$, $p = .372$, $\eta^2 = .036$	$F(22) = 1.265$, $p = .273$, $\eta^2 = .054$
Grammaticality x Condition x Anteriority	$F(22) = 3.253$, $p = .079$, $\eta^2 = .129$	$F(22) = 2.895$, $p = .097$, $\eta^2 = .116$	$F(22) = 1.857$, $p = .185$, $\eta^2 = .078$	$F(22) = 3.816$, $p = .058$, $\eta^2 = .148$
		Midline regions		
Grammaticality	$F(22) = 0.000$, $p = .996$, $\eta^2 = .000$	$F(22) = 0.013$, $p = .909$, $\eta^2 = .001$	$F(22) = 6.039$, $p = .022$, $\eta^2 = .215$	$F(22) = 3.925$, $p = .06$, $\eta^2 = .151$
Grammaticality x Condition	$F(22) = 0.182$, $p = .673$, $\eta^2 = .008$	$F(22) = 1.266$, $p = .273$, $\eta^2 = .054$	$F(22) = 0.073$, $p = .790$, $\eta^2 = .003$	$F(22) = 0.014$, $p = .906$, $\eta^2 = .001$
Grammaticality x Anteriority	$F(22) = 1.733$, $p = .198$, $\eta^2 = .073$	$F(22) = 0.132$, $p = .798$, $\eta^2 = .006$	$F(22) = 1.101$, $p = .328$, $\eta^2 = .048$	$F(22) = 14.196$, $p < .001$, $\eta^2 = .392$
Grammaticality x Condition x Anteriority	$F(22) = 5.838$, $p = .018$, $\eta^2 = .210$	$F(22) = 4.444$, $p = .033$, $\eta^2 = .168$	$F(22) = 2.463$, $p = .121$, $\eta^2 = 0.101$	$F(22) = 3.282$, $p = .074$, $\eta^2 = 0.130$.

Note: The top part of the table shows the results for the ANOVAs with the lateral regions of interest and had grammaticality (2 levels: grammatical and ungrammatical), hemisphere (2 levels: left and right hemisphere), and anteriority (3 levels: anterior, central, and posterior) as between-subject factors. The second part of the table shows the repeated measures ANOVAs that only looked at the regions of interest in the midline regions and had grammaticality (2 levels: grammatical and ungrammatical), and anteriority (3 levels: anterior, central, and posterior) as within-subject factors. As an effect size statistic for the ANOVA analyses, we report partial eta squared (η^2).

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SUMMARY

This PhD thesis investigates the processing of agreement violations in Dutch adults with dyslexia when reading or listening to sentences, and compares their performance to that of Dutch adults without dyslexia. In particular, we focused on the processing of gender and number (dis)agreement using event-related potentials (ERPs) and subject-verb (dis)agreement using self-paced reading (SPR). The ERP and SPR data were supplemented with behavioral measures (i.e., accuracy on the grammaticality judgement task).

Chapter 1 begins with a general introduction, establishing the topic and providing a theoretical and methodological framework for the thesis. This chapter first provides an overview of the definitions and etiology of dyslexia, as well as the characteristics of adults with dyslexia, the population under investigation. This is followed by a description of the different theories on morphosyntactic processing in dyslexia. The subsequent sections focus on the description of the methods used in the thesis: ERPs and SPR, as well as a description of the relevant ERP components. Three major ERP components have been identified in sentence processing research: the LAN and the P600 (typically associated with morphosyntactic processing), and the N400 (traditionally related to the processing of semantics). Special emphasis was placed on studies on agreement violation processing in dyslexia that elicited these ERP components. The last part of this chapter elaborates on the linguistic background of the two types of linguistic structures under investigation: gender and number (dis)agreement and subject-verb (dis)agreement in Dutch.

After providing a theoretical and methodological basis, Chapter 1 ends with outlining the four research questions of the thesis. The first two research questions focused on the differences in performance between adults with and without dyslexia. The first question is related to the behavioral grammaticality judgement task used in all three studies in the thesis: (1) Is there a difference between adults with and without dyslexia on a behavioral grammaticality judgement task? The second research question concerns the first two experiments conducted with ERPs: (2) Does the neurophysiological pattern (as measured with ERPs) during processing of morphosyntactic information differ between adults with and without dyslexia? The last two research questions were related to the performance of adults with dyslexia. Thus, the third research question was related to the ERP experiments: (3) Is there a processing difference between reading and listening to the same stimuli for adults with dyslexia? Finally, the last research question focused on the different types of disagreement (within-phrase gender and number disagreement in the two ERP experiments and across-phrase subject-verb disagreement in the SPR experiment): (4) Is there a difference between within-phrase and across-phrase disagreement processing for adults with dyslexia?

Chapter 2 presented an ERP listening experiment in Dutch adults with dyslexia. The first goal of the experiment in Chapter 2 was to examine the differences in the latency and the distribution of the ERP effects between adults with and without dyslexia in processing auditorily presented stimuli containing either gender or number disagreement. The results of adults with dyslexia were compared qualitatively to the behavioral and ERP results of adults without dyslexia by Popov (2017). As expected, our findings show that there is a difference in processing agreement violations between the two groups, which was reflected by the difference in latency and different ERP component characteristics between the groups. More specifically, listening to sentences containing gender disagreement elicited no ERP effect for adults with dyslexia, while a frontal negativity was found for number disagreement. The puzzling finding of a frontal negativity in response to number disagreement could be interpreted as a potential LAN-like component, reflecting violation detection, or as a compensatory mechanism used by adults with dyslexia to support their difficulties with morphosyntactic processing. For adults without dyslexia, Popov (2017) reported a LAN-P600 pattern in the gender condition, and a P600, associated with sentence reanalysis/repair, only in the number condition. The absence of an ERP effect in the gender condition for adults with dyslexia indicates that they are less sensitive to the violation in the gender condition compared to adults without dyslexia. The onset of the effect in the gender condition was also delayed in adults with dyslexia compared to adults without dyslexia. Thus, compared to adults without dyslexia, adults with dyslexia exhibit atypical processing of gender and number disagreement using ERPs. The second goal of the experiment from Chapter 2 was to compare the ERP responses to gender and number disagreement in the group of adults with dyslexia. Due to the nature of the violations and the difference in perceptual salience between the two conditions, we assumed that adults with dyslexia will have more difficulty detecting the violation in the gender compared to the number condition. The results were in line with our prediction, since no ERP effect was elicited in the gender condition, while a frontal negativity was present in the number condition for adults with dyslexia. We also expected number to be more complex to repair than gender due to the presence of multiple repair options. Our results are inconclusive regarding the structural repair mechanisms in spoken stimuli in adults with dyslexia, since no P600 was elicited in response to gender or number disagreement.

The experiment presented in **Chapter 3** was a replication of the experiment in Chapter 2 in the visual modality. The first goal was to compare the performance of adults with and without dyslexia in response to visually presented gender and number disagreement, as measured with ERPs. As predicted, our results show group differences in processing gender and number disagreement. In the group of adults with dyslexia, sentences containing gender disagreement elicited a P600, while sentences containing number disagreement elicited a frontal negativity and a P600. Due to its latency, this unexpected finding of a frontal negativity is most likely not a 'true' LAN, but rather related to the recognition of the following word or late morphosyntactic integration. The results of adults with dyslexia were compared qualitatively to the behavioral and ERP results of adults without dyslexia (Popov & Bastiaanse, 2018). For adults without dyslexia, both gender and number disagreement elicited a P600 only. Both in the gender and the number condition, the onset of the ERP effect was approximately 200 ms later in the dyslexia group than in the group without dyslexia. The differences in the time course and the ERP patterns between the groups indicate that agreement violation processing in adults with dyslexia is slower and atypical compared to adults without dyslexia. The second goal of the experiment in Chapter 3 was to compare the ERP responses of adults with dyslexia to sentences containing gender disagreement and those containing number disagreement. Since we did not see differences between the elicited P600 to gender and number disagreement in adults with dyslexia, our results are inconclusive regarding the structural repair processes in dyslexia. Our final goal in Chapter 3 was to qualitatively compare the ERP results of adults with dyslexia in response to gender and number disagreement in listening (Chapter 2) and reading (Chapter 3). The results show that presentation modality plays a role in the performance of adults with dyslexia, since different ERP components were found in listening and reading for the same stimuli.

Chapter 4 presented an SPR experiment on the processing of subject-verb disagreement in Dutch adults with and without dyslexia. Our main goal in Chapter 4 was to investigate the influence of linear distance (i.e., the number of words between the subject and the verb) as a measure of working memory (WM) load on the processing of subject-verb disagreement. We measured both accuracy on the grammaticality judgement task, as well as the reading times (RTs) in the three critical regions (i.e., the verb as the integration point, the spill-over region immediately following the verb, and the final word) for the two groups. Firstly, we compared the performance of adults with and without dyslexia on the grammaticality judgement task. As predicted, our findings show that, although both groups perform close-to-ceiling on accuracy, adults with dyslexia have an overall lower accuracy than adults without dyslexia on this task. Secondly, we investigated whether there was a difference in accuracy on the grammaticality judgement task for different levels of distance (short vs. long) and grammaticality (grammatical vs. ungrammatical) in the group of adults with dyslexia. Contrary to our predictions, our results show that adults with dyslexia were not influenced by either linear distance or ungrammaticalities on the grammaticality judgement task. Finally, we compared the RTs of the two groups in terms of distance and grammaticality in the three critical regions. Given the common WM problems in dyslexia, we expected adults with dyslexia to show longer RTs for the three critical regions in the long-distance condition. Furthermore, assuming that adults with dyslexia do not readily notice ungrammaticalities in sentences, we predicted that adults with dyslexia will show no difference in RTs in the three critical regions. The results show that both adults with and without dyslexia display longer RTs for the integration point (i.e., verb) and the spill-over region following the verb. However, only adults with dyslexia exhibited longer RTs for the final word in the long- than in the short-distance condition, associated with syntactic integration difficulty at the end of the sentence. Therefore, an increase in linear distance between the subject and the verb leads to longer RTs in the three critical regions, rather than lower accuracy, in the group with dyslexia.

The thesis ends with **Chapter 5**, which contains the general discussion and conclusions, as well as the implications and directions for future research. In this chapter, the four main research questions are presented and discussed in relation to the findings of the three experiments. Concerning research question 1, we can confirm that there is a difference in performance between adults with and without dyslexia on the behavioral grammaticality judgement task. While both adults with and without dyslexia performed close-to-ceiling on this task, adults with dyslexia still performed more poorly than adults without dyslexia on the task in all three studies. Regarding research question 2, the results show group differences in the ERP patterns between adults with and without dyslexia in response to gender and number disagreement in both listening and reading. This indicates that adults with dyslexia process agreement violations differently than adults without dyslexia. In relation to research question 3, we found an ERP processing difference between reading and listening to the same stimuli for adults with dyslexia, which means that presentation modality plays a role in agreement violation processing in adults with dyslexia. Finally, concerning research question 4, our findings suggest that there are no large differences between the two types of disagreement. We see that adults with dyslexia exhibit slower processing of both within-phrase gender and number disagreement using ERPs and between-phrase subject-verb disagreement using SPR. Thus, both ERPs and SPR emerge as sensitive methods of examining agreement violation processing in adults with dyslexia, as well as differences in agreement violation processing between adults with and without dyslexia.

SAMENVATTING

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Dit proefschrift onderzoekt de verwerking van grammaticale schendingen bij het lezen of luisteren naar zinnen bij Nederlandse volwassenen met dyslexie, en vergelijkt hun prestaties met die van Nederlandse volwassenen zonder dyslexie. We hebben ons met name gericht op de verwerking van geslachts- en getalsincongruentie met *event-related potentials* (ERP's) en subject-werkwoordsincongruentie met *self-paced reading* (SPR). De ERP- en SPR-gegevens werden aangevuld met gedragsmetingen (accuratesse op de grammaticale beoordelingstaak).

Hoofdstuk 1 begint met een algemene introductie, waarin het onderwerp wordt vastgesteld en een theoretisch en methodologisch kader voor het proefschrift wordt gegeven. Dit hoofdstuk geeft eerst een overzicht van de definities en etiologie van dyslexie, evenals de kenmerken van volwassenen met dyslexie, de onderzochte populatie. Daarna volgt een beschrijving van de verschillende theorieën over morfosyntactische verwerking bij dyslexie. De daaropvolgende paragrafen richten zich op de beschrijving van de methoden die in het proefschrift worden gebruikt: ERP's en SPR, evenals een beschrijving van de relevante ERP-componenten. Drie belangrijke ERP-componenten zijn geïdentificeerd in de onderzoeksliteratuur naar zinsverwerking: de LAN en de P600 (meestal geassocieerd met morfosyntactische verwerking) en de N400 (traditioneel gerelateerd aan de verwerking van semantiek). Speciale aandacht wordt besteed aan studies betreffende de schendingen die bij dyslexie deze ERP componenten als gevolg hebben. Het laatste onderdeel van dit hoofdstuk gaan dieper in op de linguïstische achtergrond van de twee soorten taalstructuren die worden onderzocht: geslachts- en getals(in)congruentie en subject-werkwoords(in) congruentie in het Nederlands.

Na het verschaffen van een theoretische en methodologische basis, eindigt Hoofdstuk 1 met het schetsen van de vier onderzoeksvragen van het proefschrift. De eerste twee onderzoeksvragen zijn gericht op de verschillen in prestatie tussen volwassenen met en zonder dyslexie. De eerste vraag heeft betrekking op de grammaticale beoordelingstaak die in alle drie onderzoeken in het proefschrift is gebruikt: (1) Is er een verschil tussen volwassenen met en zonder dyslexie op een grammaticale beoordelingstaak? De tweede onderzoeksvraag betreft de eerste twee experimenten die met ERP's zijn uitgevoerd: (2) Verschilt het neurofysiologische patroon (zoals gemeten met ERP's) tijdens de verwerking van morfosyntactische informatie tussen volwassenen met en zonder dyslexie? De laatste twee onderzoeksvragen waren gericht op het functioneren van volwassenen met dyslexie. De derde onderzoeksvraag had betrekking op de ERP-experimenten: (3) Is er een verwerkingsverschil tussen lezen en luisteren naar dezelfde stimuli voor volwassenen met dyslexie? Ten slotte richtte de laatste onderzoeksvraag zich op de verschillende soorten incongruentie (geslachts- en getalsincongruentie in de twee ERP-experimenten en subject-werkwoordsincongruentie in het SPR-experiment): (4) Is er een verschil tussen de verwerking van incongruentie binnen een zinsdeel (NP) en tussen zinsdelen (NP en VP) voor volwassenen met dyslexie?

Hoofdstuk 2 toont een ERP-luisterexperiment bij Nederlandse volwassenen met dyslexie. Het eerste doel van het experiment in Hoofdstuk 2 was om de verschillen in het tijdsverloop en de ERP-effecten tussen volwassenen met en zonder dyslexie te onderzoeken bij het verwerken van auditief gepresenteerde stimuli die geslachts- en getalsincongruentie bevatten. De resultaten van volwassenen met dyslexie werden kwalitatief vergeleken met de gedrags- en ERP-resultaten van volwassenen zonder dyslexie (Popov, 2017). Zoals verwacht, laten onze bevindingen zien dat er een verschil is tussen de twee groepen in de verwerking van grammaticale schendingen, wat tot uiting kwam in het verschil in het tijdsverloop en de eigenschappen van de verschillende ERP-componenten tussen de groepen. Meer specifiek, het luisteren naar zinnen die geslachtsincongruentie bevatten, veroorzaakte geen ERP-effect voor volwassenen met dyslexie, terwijl een frontale negativiteit werd gevonden voor getalsincongruentie. De onverwachte bevinding van een frontale negativiteit als reactie op getalsincongruentie kan worden geïnterpreteerd als een potentiële LAN-achtige component, die de detectie van grammaticale schendingen weerspiegelt, of als een compensatiemechanisme dat wordt gebruikt door volwassenen met dyslexie om hun problemen met morfosyntactische verwerking te ondersteunen. Voor volwassenen zonder dyslexie rapporteerde Popov (2017) een LAN-P600-patroon in de geslachtsconditie, en een P600, geassocieerd met heranalyse/herstel van de zin, alleen in de getalsconditie. De afwezigheid van een ERP-effect in de geslachtsconditie voor volwassenen met dyslexie geeft aan dat ze minder gevoelig zijn voor de schending in de geslachtsconditie in vergelijking met volwassenen zonder dyslexie. De aanvang van het effect in de geslachtsconditie was ook vertraagd bij volwassenen met dyslexie in vergelijking met volwassenen zonder dyslexie. Kortom, vergeleken met volwassenen zonder dyslexie, vertonen de ERP's van volwassenen met dyslexie een atypische verwerking van geslachts- en getalsincongruentie. Het tweede doel van het experiment in Hoofdstuk 2 was om de ERP-reacties op geslachts- en getalsincongruentie met elkaar te vergelijken in de dyslexiegroep. Vanwege de aard van de schendingen en het verschil in perceptuele opvallendheid tussen de twee condities, gingen we ervan uit dat volwassenen met dyslexie meer moeite zouden hebben om de schending in de geslachtsconditie te detecteren in vergelijking met de getalsconditie. De resultaten waren in lijn met onze verwachting, aangezien er geen ERP-effect afwezig was in de geslachtsconditie, terwijl een frontale negativiteit aanwezig was in de getalsconditie voor volwassenen met dyslexie. We verwachtten ook dat getal complexer te herstellen zou zijn dan geslacht vanwege de aanwezigheid van meerdere herstelopties. Op basis van onze resultaten blijven de structurele herstelmechanismen in gesproken stimuli bij volwassenen met dyslexie nog onduidelijk, aangezien er geen P600 werd veroorzakt als reactie op geslachts- of getalsincongruentie.

Het experiment gepresenteerd in **Hoofdstuk 3** was een replicatie van het experiment in Hoofdstuk 2 in de visuele modaliteit. Het eerste doel was om de prestaties van volwassenen met en zonder dyslexie te vergelijken in reactie op visueel gepresenteerde geslachts- en getalsincongruentie, gemeten met ERP's. Zoals voorspeld, laten onze resultaten groepsverschillen zien in het verwerken van geslachts- en getalsincongruentie. In de groep volwassenen met dyslexie veroorzaakten zinnen met geslachtsincongruentie een P600, terwijl zinnen met getalsincongruentie een frontale negativiteit en een P600 veroorzaakten. Vanwege het tijdsverloop is deze onverwachte bevinding van een frontale negativiteit hoogstwaarschijnlijk geen 'echte' LAN, maar eerder gerelateerd aan de detectie van het volgende woord of late morfosyntactische integratie. De resultaten van volwassenen met dyslexie werden kwalitatief vergeleken met de gedrags- en ERP-resultaten van volwassenen zonder dyslexie (Popov & Bastiaanse, 2018). Voor volwassenen zonder dyslexie veroorzaakten zowel geslachts- als getalsincongruentie alleen een P600. Zowel in de geslachts- als de getalsconditie begon het ERP-effect ongeveer 200 ms later in de dyslexiegroep dan in de groep zonder dyslexie. De verschillen in het tijdsverloop en de ERP-patronen tussen de groepen geven aan dat de verwerking van schendingen bij volwassenen met dyslexie langzamer en atypisch is in vergelijking met volwassenen zonder dyslexie. Het tweede doel van het experiment in Hoofdstuk 3 was om de ERP-reacties van volwassenen met dyslexie te vergelijken tussen zinnen die geslachts- of getalsincongruentie bevatten. Omdat we bij volwassenen met dyslexie geen verschillen zagen tussen de veroorzaakte P600 voor geslachts- en getalsincongruentie, kunnen we op basis van onze resultaten geen conclusies trekken over de herstelprocessen bij dyslexie. Ons uiteindelijke doel van Hoofdstuk 3 was om de ERP-resultaten van volwassenen met dyslexie kwalitatief te vergelijken met de geslachts-getalsincongruentie resultaten met betrekking tot luisteren (Hoofdstuk 2) en lezen (Hoofdstuk 3). De resultaten laten zien dat presentatiemodaliteit een rol speelt in de prestaties van volwassenen met dyslexie, omdat er verschillende ERP-componenten worden gevonden bij luisteren en lezen voor dezelfde stimuli.

Hoofdstuk 4 presenteerde een SPR-experiment over de verwerking van subject-werkwoordsincongruentie bij Nederlandse volwassenen met en zonder dyslexie. Ons belangrijkste doel in Hoofdstuk 4 was om de invloed van lineaire afstand (d.w.z. het aantal woorden tussen het subject en het werkwoord) te onderzoeken als een maat voor de belasting van het werkgeheugen op de verwerking van subject-werkwoordsincongruentie. We maten zowel de accuratesse op de grammaticale beoordelingstaak als de leestijden in de drie ‘kritische regio’s’ (d.w.z. het werkwoord als het integratiepunt, de *spill-over* regio onmiddellijk na het werkwoord, en het laatste woord van de zin) voor de twee groepen. Ten eerste vergeleken we de prestaties van volwassenen met en zonder dyslexie op de grammaticale beoordelingstaak. Zoals voorspeld, laten onze bevindingen zien dat, hoewel beide groepen qua accuratesse bijna een plafondeffect laten zien, volwassenen met dyslexie over het algemeen een lagere accuratesse hebben op deze taak dan volwassenen zonder dyslexie. Ten tweede hebben we onderzocht of er een verschil was in accuratesse op de grammaticale beoordelingstaak voor verschillende niveaus van afstand (kort vs. lang) en grammaticaliteit (grammaticaal vs. ongrammaticaal) in de groep volwassenen met dyslexie. In tegenstelling tot onze verwachtingen, laten onze resultaten zien dat volwassenen met dyslexie op de grammaticale beoordelingstaak niet werden beïnvloed door lineaire afstand of ongrammaticaliteiten. Ten slotte vergeleken we de leestijden van de twee groepen wat betreft afstand en grammaticaliteit in de drie kritische regio’s. Aangezien werkgeheugenproblemen vaak voorkomen bij dyslexie, verwachtten we dat volwassenen met dyslexie langere leestijden zouden laten zien voor de drie kritische regio’s in de lange-afstand conditie. Bovendien, ervan uitgaande dat volwassenen met dyslexie ongrammaticaliteiten in zinnen vaak niet opmerken, voorspelden we dat volwassenen met dyslexie geen verschil in leestijden in de drie kritische regio’s zullen laten zien. De resultaten tonen aan dat zowel volwassenen met als volwassenen zonder dyslexie langere leestijden laten zien voor het integratiepunt (d.w.z. het werkwoord) en de *spill-over* regio na het werkwoord. Echter, alleen volwassenen met dyslexie vertoonden voor het laatste woord in de zin langere leestijden in de lange- dan in de korte-afstand conditie, geassocieerd met syntactische integratieproblemen aan het einde van de zin. Daarom leidt een toename van de lineaire afstand tussen het subject en het werkwoord tot langere leestijden in de drie kritische regio’s, in plaats van een lagere accuratesse in de groep met dyslexie.

Het proefschrift eindigt met **Hoofdstuk 5**, dat de algemene discussie en conclusies bevat, evenals de implicaties en richtingen voor toekomstig onderzoek. In dit hoofdstuk worden de vier hoofdonderzoeksvragen gepresenteerd en besproken in relatie tot de bevindingen van de drie experimenten. Met betrekking tot onderzoeksvraag 1 kunnen we bevestigen dat er een verschil is in prestatie tussen volwassenen met en volwassenen zonder dyslexie op de grammaticale

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beoordelingstaak. Alhoewel zowel volwassenen met als volwassenen zonder dyslexie bijna een plafondeffect op deze taak lieten zien, presteerden volwassenen met dyslexie in alle drie onderzoeken nog steeds slechter dan volwassenen zonder dyslexie. Met betrekking tot onderzoeksvraag 2 laten de resultaten groepsverschillen zien in de ERP-patronen tussen volwassenen met en volwassenen zonder dyslexie als reactie op geslachts- en getalsincongruentie bij zowel luisteren als lezen. Dit geeft aan dat volwassenen met dyslexie grammaticale schendingen anders verwerken dan volwassenen zonder dyslexie. Met betrekking tot onderzoeksvraag 3 vonden we een ERP-verwerkingsverschil tussen lezen en luisteren naar dezelfde stimuli voor volwassenen met dyslexie, wat betekent dat presentatiemodaliteit een rol speelt bij de verwerking van grammaticale schendingen bij volwassenen met dyslexie. Ten slotte, met betrekking tot onderzoeksvraag 4, suggereren onze bevindingen dat er geen grote verschillen zijn tussen de twee congruentietypen. Wel zien we dat volwassenen met dyslexie een langzamere verwerking vertonen van geslachts- en getalsincongruentie binnen een NP met ERP's, als ook tussen een NP en een VP voor subject-werkwoordsincongruentie met SPR.

Zo komen zowel ERP's als SPR naar voren als gevoelige methoden om de verwerking van schendingen bij volwassenen met dyslexie te onderzoeken, evenals verschillen in de verwerking van schendingen tussen volwassenen met en zonder dyslexie.

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