Agreement Processing in Dutch Adults with Dyslexia

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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$_{\text{C(ommon)}}$
'The beautiful bicycle'

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

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

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