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THE LINGUISTIC NATURE OF DEVELOPMENTAL DYSLEXIA: AN ELECTROPHYSIOLOGICAL AND BEHAVIOURAL INVESTIGATION

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*“No problem is so complicated
that you cannot make it more complicated”*

Andrew Grove

“Simple answers, no science”

Noam Chomsky

General overview

The acquisition of reading represents an important step in child development. Although the majority of children have no problem when they are taught to read, a small proportion of children fail to acquire this skill according to the normal timetable. These children suffer from Developmental Dyslexia (DD), a disorder that has been widely studied. However, from the vast amount of literature on DD a very complex picture emerges. Deficits associated with this disorder are very heterogeneous and hypotheses concerning the aetiology of DD cover most of the domain of cognition.

The goal of the present dissertation is to highlight and investigate the linguistic nature of DD. Language is a complex multi-faced system that comprises different sub-domains. Within the linguistic domain, phonology has been largely investigated in the literature on DD, with an almost universal consensus on the role of phonological deficits in reading impairments. Other aspects of language have received less attention in the study of DD. The few studies that have focused on broader linguistic skills in DD (including morphology, syntax, and to a lesser degree semantics) show that linguistic problems are not restricted to the written language, but are evident in spoken language too. Moreover, the fact that DD is often associated with Specific Language Impairment (SLI) further strengthens the idea that the linguistic impairment in DD might go beyond decoding written language.

The present dissertation investigates the nature of linguistic impairments in DD. In particular, phonological and morphosyntactic skills, as well as their relationship, have been investigated, providing direct comparison to SLI plus DD. In order to do that, Event-Related brain Potentials (ERPs) have been used, a particularly sensitive measure which provides on-line information about linguistic processing with an excellent temporal resolution, thus revealing mild anomalies that might not be found in behavioural tasks.

The present dissertation is structured as follows.

First, a brief introduction on DD, with a specific focus on the linguistic nature of the disorder, is provided. The existing evidence for weakness in oral language development - in particular in (morpho)syntactic skills - in individuals with DD are reviewed and discussed. The review of the literature has been structured considering an approach which suggests that (morpho)syntactic deficits in DD might be due to an underlying phonological impairment (Shankweiler & Crain, 1990). Furthermore, the diagnostic category of Specific Language Impairment (SLI) is presented, with the aim of investigating the similarities and differences in the cognitive profiles of the two developmental disorders. The relationship between the two types of language impairment is discussed, in light of models proposed to account for the cognitive and diagnostic overlap. Finally, the general research questions of the dissertations are presented.

Second, a brief introduction to ERPs is provided. The technique in itself is presented, particularly concerning the methods for computing and extracting ERPs from the superimposed electroencephalogram (EEG). Further, the main ERP components associated with language processing are described, providing a brief overview of their functional interpretation. Particular emphasis is on the ERP correlates of subject-verb agreement violations as it is the paradigm used for the studies presented in the experimental section. After this general introduction, a brief overview of the ERP studies addressing language acquisition is provided, again with a special emphasis on morphosyntactic processing. A detailed review of ERP studies conducted on individuals with DD and SLI is then presented. The final section describes the advantages and disadvantages of the ERP technique in relation to other techniques and outlines the reasons why this technique was chosen for the investigation of subtle linguistic deficits in DD.

After the general introduction, three studies are presented.

In Study 1¹, ERPs were used in order to compare morphosyntactic processing in Italian adults with DD (aged 20-28 years) and unimpaired controls. Sentences including subject-verb agreement violations were auditorily presented, with grammaticality and subject number as main factors. The presence of electrophysiological anomalies in the DD group is discussed in light of the hypothesis of a linguistic deficit and of different language processing modalities in DD participants.

In Study 2, three groups of Italian children (aged 8-12 years) including children with DD without any history of language impairment, children with a co-diagnosis of DD and SLI, and control children matched on chronological age were tested using the same paradigm of Study 1, and additional behavioural tests on phonological and morphosyntactic processing. The presence of an indefinite border between the two disorders is discussed, within the framework of a *multiple overlapping risk factor* model, proposed in opposition to single deficit approaches to developmental disorders (Pennington & Bishop, 2009)

In Study 3², the interaction between phonological/auditory and morphosyntactic processing was investigated in German speaking adults with DD (aged 19-28 years) and matched unimpaired control participants. Short German sentences - either correct or containing a morphosyntactic violation - were auditorily presented while ERPs were recorded. The verbal inflections were manipulated to consist of three different levels (low, medium, high) of acoustic salience. In addition, phonological processing was tested with behavioural tasks and with an ERP experiment on phonemic discrimination.

Finally, the findings from the different experiments are briefly reviewed and discussed in relation to the research aims, in order to elucidate the scientific contribution of this dissertation.

¹ A modified version of this Chapter has been submitted for publication as C.Cantiani, M. L. Lorusso, P. Perego, M. Molteni, M.T. Guasti, *ERPs reveal anomalous morphosyntactic processing in Developmental Dyslexia*.

² This study has been carried out at the *Max Plank Institute for Human Cognitive and Brain Sciences* in Leipzig (Germany), under the supervision of Prof. Angela Friederici. A modified version of this Chapter will be submitted for publication as C. Cantiani, C. Männel, B. Sabisch, M. L. Lorusso, M. T. Guasti, A. D. Friederici, *Characterizing the morphosyntactic processing deficit and its relationship to phonology in Developmental Dyslexia*.

Chapter 1

Developmental Dyslexia: The linguistic nature of the disorder in comparison to Specific Language Impairment

1.1 General introduction on Developmental Dyslexia

Developmental Dyslexia (DD) is a specific and persistent difficulty in acquiring adequate reading skills, in spite of average intelligence and adequate education and socio-cultural opportunities. It is one of the most frequent diagnosed learning disabilities and the estimate of prevalence in Italian children ranges from 3 to 5% (Cornoldi, 1991; Stella, 1999).

DD usually becomes apparent in the first school years as soon as children learn to read. Difficulties with reading will persist throughout the adult life, but some adults may overcome these difficulties by developing compensatory strategies.

The genetic basis of DD has been demonstrated in several studies (for a review see Fisher & DeFries, 2002). For example, we know that monozygotic twins share a diagnosis of DD more frequently (68% vs. 39%) than dizygotic twins. Furthermore, it has been estimated that a child with a dyslexic parent has approximately a 50% risk of acquiring the disorder.

The difficulties that dyslexic individuals encounter in reading are indeed the core deficit of the disorder, and the hints that lead to a clinical diagnosis. However, they are just the tip of the iceberg, as they probably constitute only the most visible dysfunction of a multifactorial disorder (Menghini et al., 2010; Pennington, 2006). In fact, several cognitive functions were shown to be specifically impaired in DD. First of all, the presence of deficits in phonological processing is undisputed (see Section 1.2.1). In addition, deficits involving different cognitive domains have been found in dyslexic individuals, including auditory processing (Tallal, 1980), visual perception (e.g., J. Stein & Walsh, 1997), visual and auditory attention (e.g., Facoetti et al., 2003), motor control and automatisations (Nicolson & Fawcett, 1990). Given the fact that the focus of the present dissertation

is on the linguistic nature of DD, the *phonological deficit hypothesis* and the *auditory temporal processing hypothesis* will be extensively described in the next Sections (1.2.1.1 and 1.2.1.2). Other theories will be only briefly introduced here, in order to provide a complete picture of the complex theoretical background concerning DD.

The *visual theory* reflects a longstanding tradition in the study of DD. According to this theory, a visual impairment gives rise to difficulties with the visual processing of letters and words. This might take the form of unstable binocular fixations and poor vergence (e.g., Cornelissen, Bradley, Fowler, & Stein, 1991), as well as increased visual crowding (Spinelli, De Luca, Judica, & Zoccolotti, 2002). At anatomical level, the theory postulates a deficit in the transient (Magnocellular) visual system which is responsible for processing stimuli with high temporal and low spatial frequencies (Lovegrove, Bowling, Badcock, & Blackwood, 1980).

A different view is represented by the *automaticity/cerebellar theory* (Nicolson & Fawcett, 1990). According to this theory, deficits in the automatization of reading and of its component functions (such as grapheme-to-phoneme conversion) are assumed to be due to deficient cerebellar functioning. Furthermore, the cerebellar dysfunction, confirmed by imaging studies (Nicolson et al., 1999), plays a role in motor control and therefore in speech articulation, probably leading to deficient phonological representations. Support for the cerebellar theory comes from evidence of poor motor coordination and poor balance in dyslexic children (Nicolson & Fawcett, 1990).

Recently, an *attentional hypothesis* has also been proposed (e.g., Facoetti et al., 2003; Hari & Renvall, 2001). Attentional deficits are thought to interfere with the encoding of a sequence of letters, resulting in the confusion of letters and visual word forms. Interestingly, attentional deficits can be dissociated from phonological deficits, and both types of deficits are valid predictors for reading disabilities (Valdois, Bosse, & Tainturier, 2004).

Finally, the *Magnocellular Theory* (J. Stein & Walsh, 1997) attempts to unify different theories. Since the Magnocellular component of the visual system (Lovegrove et al., 1980) also projects to the parietal areas subserving spatial attention, as well as to the cerebellum, it may account for most of the deficits in visual perception, visual attention and motor control/automatization found in DD. In addition, this theory has been generalised to other modalities, particularly to the auditory one (J. Stein & Walsh, 1997). A subsystem responsible for the analysis of acoustic transients has been identified. Galaburda, Menard, and Rosen (1994) showed that, like visual magnocells, auditory magnocells in the medial geniculate nucleus are abnormal in dyslexic brains. It results that both auditory (see Section 1.2.1.2) and visual disorders in DD could be part of a more general magnocellular dysfunction.

Given the existence of different deficits, a *multiple neurocognitive deficit model* seems necessary to understand DD (Pennington, 2006). Although many studies have proved the existence of

individual neurocognitive deficits in DD, only a few have tested these different deficits simultaneously in a single study (Heim et al., 2008; Menghini et al., 2010; Ramus et al., 2003). For example, a paradigmatic study was conducted by Ramus et al. (2003) to test the phonological, magnocellular and cerebellar theories. All 16 adults with DD included in the study showed phonological impairments, while other disorders, when present, were interpreted as a mere aggravation, associated with the phonological impairment. More recently, Menghini et al. (2010) explored different cognitive domains (including phonology, visual-spatial perception, motion perception, visuo-spatial and auditory attention, executive functions and implicit learning) in a wide sample of children with DD to assess their neuropsychological profile. Based on the results, the authors conclude that “*DD is a complex disorder caused by different heterogeneous impairments in neuropsychological functioning*” (Menghini et al., 2010, p. 869).

1.2 The linguistic nature of Developmental Dyslexia

According to the International Dyslexia Association, DD is a specific *language-based* disorder. As recent models highlight, reading, writing and oral language, involving both comprehension and production, may be considered as different functional systems of the unitary phenomenon of language (*language by eye, by hand, by ear and by mouth*; Berninger, Abbott, Abbott, Graham, & Richards, 2002). Regarding oral language skills, phonology has been the component that has received more attention (see Section 1.2.1). Problems with other domains of spoken language are however not uncommon in dyslexic individuals: they may find it difficult to express concepts clearly or to fully comprehend what others mean when they speak. Such language difficulties are usually subtle (and difficult to recognise), but they can lead to significant problems.

The next sections will provide an overview of the existing evidence for weakness in oral language development.

1.2.1 DD and phonology

1.2.1.1 The phonological deficit hypothesis

The *phonological deficit hypothesis* (Ramus et al., 2003; Snowling, 2000) is the best-known and most long standing explanation for DD, pointing to a deficit in the representation and processing of speech sounds. Learning to read requires to map letters to mental representations of the corresponding basic speech sounds (phonemes). Reading a new, unfamiliar word requires to

identify its phonemic constituents, assemble the phonemes and utter the word. Evidence for a phonological impairment in DD has been well documented.

Dyslexia is associated with difficulties in tasks that require deliberate activation and manipulation of speech units. **Phonological awareness** can be assessed through tasks requiring to identify the “odd-one-out” word in a list, on the basis of the onsets or codas, and through tasks requiring an active production, such as phoneme deletion (“repeat *sit* without the /s/”) or synthesis (“which word is /s/ /i/ /t/”) (Bradley & Bryant, 1983; Stanovich & Siegel, 1994). Several studies have shown that dyslexic children fail in tasks that test phonological awareness (e.g., Rispens, 2004; Snowling, 2000; Vellutino, Fletcher, Snowling, & Scanlon, 2004), and this impairment seems to persist into adulthood (Bruck, 1992; Ramus et al., 2003). Furthermore, at-risk children are also reported to fail tasks tapping phonological awareness (e.g., De Bree, 2007; Gallagher, Frith, & Snowling, 2000; Scarborough, 1990). In addition, the relationship between reading and phonological awareness has been further confirmed by the evidence that interventions to enhance phonological awareness allow one to improve reading performances (Bradley & Bryant, 1983).

Deficits have also been demonstrated in tasks depending on implicit phonological processing. In particular, **verbal Short-Term Memory** (STM; Jorm, 1983), which is the cognitive component responsible for the storage of phonological forms, has often been found to be impaired in dyslexic individuals. Although verbal STM can be measured in various ways (i.e., digit span tasks), using meaningful information may not be the best way, since “top-down” knowledge may positively interfere with performance. The **non-word repetition** task (Stone & Brady, 1995) may be a better task, as it measures more directly the ability to hold a phonological code in short-term memory. Participants are required to repeat words that are phonologically plausible, but not present in the lexicon. A non-word repetition deficit appears to be present in dyslexic children (e.g., Kahmi & Catts, 1986; Rispens, 2004), in children at genetic risk of dyslexia (Carroll & Snowling, 2004; De Bree, 2007; Gallagher et al., 2000) as well as in dyslexic adults (Ramus et al., 2003). In addition, **Working Memory** (W.M.; Baddeley, 1986), i.e., the capacity to store and manipulate information over brief periods of time, has also been found to be impaired in DD (Nicolson, Fawcett, & Baddeley, 1992).

Finally, a third widely demonstrated deficit in DD concerns **Rapid Automatic Naming** (Catts, 1986). Dyslexic children exhibit more problems in comparison to age-matched control children, when required to rapidly name objects, colours and letters (Wolf et al., 2002). Furthermore, previous studies demonstrated that RAN performances predicted unique variance in poor readers’ reading rate and overall reading achievement. Although some authors consider deficit in phonological awareness and in rapid automatic naming as different and independent impairments (as in the Double Deficit Hypothesis proposed by Wolf & Bowers, 1999), others propose that they

all are, together with short-term memory, dimension of the same deficit in accessing phonological representations (Ramus & Szenkovits, 2008).

In addition to behavioural evidence, phonological deficits in DD are also supported by a large number of anatomical and neuroimaging studies that report hypoactivation and brain abnormalities in dyslexics' left posterior temporal areas (perisylvian regions), classically considered to be involved in phonological processing (Rumsey et al., 1992).

1.2.1.2 The Auditory Temporal Processing Hypothesis

Based on this short review of phonological impairments in DD, the existence of a phonological deficit and its contribution to reading disorders is not disputed. What is still unclear is the nature of these difficulties. Some researchers challenge the specificity of the phonological deficit, and postulate that it is secondary to a more basic auditory deficit. Notably, Tallal (1980) proposed that phonological processing difficulties result from a "temporal processing deficit". According to this hypothesis, dyslexic children are impaired in their ability to perceive auditory stimuli that have short duration and occur in rapid succession. Most speech sounds involve brief, rapidly succeeding intra-syllabic acoustic changes. Such a deficit at the auditory level could compromise the temporal analysis of speech at the phoneme level, and thus the building of correct phoneme representations. With such constraints, the development of language skills, both oral and written, would be difficult.

Compatible to Tallal's hypothesis (1980), several studies show that dyslexic individuals have difficulties in extracting discrete phonological representations from phonetic features embedded within the speech signal (e.g., Manis et al., 1997; Serniclaes, Sprenger-Charolles, Carre, & Demonet, 2001). In addition to behavioural studies, several electrophysiological experiments using Mismatch Negativity (MMN) paradigms confirmed the presence of phonemic discrimination deficit in DD (see Section 2.5.1 for an extensive review).

The issue of whether impaired phonemic discrimination is speech-specific (due to a phonological processing deficit) or is based on a more general impairment in auditory processing is still controversial (e.g., Mody, Studdert-Kennedy, & Brady, 1997). However, the growing number of behavioural and electrophysiological studies showing deficits in the discrimination and reproduction of non-speech stimuli points towards a more general and basic problem in auditory processing (Baldeweg, Richardson, Watkins, Foale, & Gruzelier, 1999; Kujala et al., 2006; Vandermosten et al., 2010). Deficits in processing rapid and short non-verbal stimuli have also been reported in dyslexic individuals speaking transparent languages such as Italian (Cantiani, Lorusso, Valnegri, & Molteni, 2010) and German (Schulte-Körne, Deimel, Bartling, & Remschmidt, 1999).

1.2.2 DD and grammatical impairment

Although the majority of studies investigating linguistic skills in DD have focused on phonology, some researchers have explored other “high-linguistic” functions, in search of broader linguistic deficits. In particular, (morpho)-syntactic skills have been investigated, both in individuals (children and adults) with DD and in younger children at risk for DD. These latter studies, mostly conducted on preschool children who haven’t started the formal acquisition of literacy and haven’t developed the reading disorder yet, are particularly important, since they suggest that it is not the lack of exposure to printed text that hampers language development.

1.2.2.1 Grammatical deficits in children at-risk for DD

Studies conducted on preschool children at genetic risk for DD have reported language delays, specifically concerning the perception and production of grammatical morphology (P. Lyytinen, Poikkeus, Laakso, Eklund, & Lyytinen, 2001; Rispens, 2004; Scarborough, 1990; van Alphen et al., 2004; Wilsenach, 2006).

Scarborough (1990) conducted a groundbreaking study testing (morpho)syntactic skills in children at-risk for DD, using the Mean Length of Utterances (MLU) and the Index of Productive Syntax as indexes of length and complexity of the produced sentences. She followed the development of 32 at-risk children from 30 to 60 months, and assessed their reading skills at the age of 8. Retrospective analyses showed that from the age of 30 until 48 months, at-risk children (later classified as DD by the age of 8 years) produced shorter and less complex sentences compared to control children. In line with these general results, Lyytinen and colleagues (2001) also reported a group of 24 month-old at-risk children producing significantly shorter sentences as measured by MLU in morphemes. Scarborough (1990) also found that syntactic skills were a very strong predictor of reading disabilities, even stronger than phonological skills. Similarly, Gallagher, Frith and Snowling (2000) found that preschool syntactic ability was a significant predictor of reading at 8 years. However, in Scarborough’s study, the differences between children at-risk for DD and control children in the considered syntactic measures disappeared at 60 months of age. One of the hypothesis proposed by Scarborough to explain this latter finding deals with the measures used for the assessment, not sensitive enough to reveal any morphosyntactic difficulties in 5 year olds. To test this hypothesis, Rispens (2004) used a more sensitive measure of morphosyntactic skills, namely a grammaticality judgement task, to assess the degree of sensitivity to subject-verb agreement violations in 5 and 6-year-old children at-risk for DD. Rispens’ results effectively revealed more problems in at-risk children compared to controls, and the author’s conclusions underlie the important role of the methodology in the assessment of morphosyntactic difficulties in children at-risk for DD.

In another longitudinal study, Van Alphen and colleagues (2004) compared the developmental linguistic profile of Dutch children at-risk for DD with that of age-matched controls. Within the morphosyntactic domain, they tested the comprehension and production of grammatical morphology. Using a preferential listening task, they found that children at-risk for DD (aged 19 and 25 months) could not discriminate between grammatical and ungrammatical sentences involving the violation of the auxiliary selection (*De boer heft gewerkt [the farmer has worked]* vs. **De boer kan gewerkt [the farmer can worked]*), while age-matched controls could. However, using similar stimuli Wilsenach (2006) showed that children at-risk for DD aged around 5 years old were as good as their age-matched controls in distinguishing between the same sentences. The same children were however significantly worse in distinguishing sentences like (*De boer heft gewerkt [the farmer has worked]*) from sentences containing a bare participle like (*De boer__ gewerkt [the farmer __ worked_{part}]*). Again, this result points toward the important role of the methodology: difficulties that seemed to be compensated emerged when using more sensitive instruments³. Furthermore, as far as the production of grammatical morphology is concerned, Van Alphen and colleagues (2004) additionally tested 3-year-old children at-risk for DD children, and age-matched controls. Two elicited sentence completion tasks, requiring as a target the plural form of nouns (*Dit is een bal en dit zijn twee ...? [this is a ball and these are two ...?]*) or inflected verbs (*Deze beer loopt en deze beer ...? [this bear walks and this bear ...?]*) were administered. The results indicated that children at-risk for DD produced fewer correct forms when compared to control children, in both tasks.

1.2.2.2 Grammatical deficits in children and adults with DD

More studies have investigated the morphosyntactic and syntactic skills in DD populations. Impaired comprehension and/or production of complex syntactic constructions, such as relative clauses or passive sentences, have been reported in dyslexic children and adults (Barshalom, Crain, & Shankweiler, 1993; Leikin & Assayag-Bouskila, 2004; Mann, Shankweiler, & Smith, 1984; Robertson & Joanisse, 2010; Smith, Macaruso, Shankweiler, & Crain, 1989; C. L. Stein, Cairns, & Zurif, 1984; Waltzman & Cairns, 2000; Wiseheart, Altmann, Park, & Lombardino, 2009). In addition, recent studies revealed lack of sensitivity to subject-verb agreement morphology (Jiménez et al., 2004; Rispens, Roeleven, & Koster, 2004), impaired inflectional morphology (Altmann, Lombardino, & Puranik, 2008; Joanisse, Manis, Keating, & Seidenberg, 2000) as well as weakness in morphological awareness tasks (Leikin & Hagit, 2006). Moreover, one of the claims that has been specifically investigated in most of these studies is the specificity of these (morpho)syntactic

³ This result might be interpreted in a different way. It could be that sensitivity to violations of the auxiliary selection is a *clinical marker* at 19 and 25 months, but not at 5 years.

deficits in DD individuals. The ‘*processing limitation hypothesis*’ proposed by Shankweiler and Crain (1986), and addressed in many of the following studies, claims that apparent syntactic deficits in DD are caused by an underlying phonological deficit.

“The syntactic component of the language apparatus appears to be intact in poor readers. The source of difficulties that might appear to reflect a syntactic deficiency must be sought elsewhere. (...) Given the abundance of evidence attesting to poor readers’ deficits in the phonological domain, there is reason to prefer the hypothesis that their comprehension problems are part and parcel of their difficulties in phonological processing. If it is correct, it would prove unnecessary to postulate additional impairment within the language system: All of problems associated with reading ultimately spring from the same source.” (Shankweiler & Crain, 1990, p. 552)

In particular, within the phonological domain, deficits in STM or WM could lead to difficulties in sentence comprehension. It is widely acknowledged that in order to comprehend spoken sentences, verbal material should be temporarily stored in a phonological code (STM) to enable further processing in WM. Presumably, if verbal material is not stored adequately, it makes the task of syntactic processing all the more difficult. As already reported (see Section 1.2.1.1), deficits in STM and WM are quite prevalent in children with DD. This raises the question of whether children with dyslexia have syntax deficits, or whether problems with syntactic processing can be explained by limitations in verbal STM and WM.

The following presentation of the existing literature on (morpho)syntactic deficits in individuals with DD will focus on this claim.

1.2.2.2.1 Comprehension/production of complex syntactic structures.

Comprehension and production of **Relative Clauses (RCs)** have been firstly investigated in children with DD (Barshalom et al., 1993; Leikin & Assayag-Bouskila, 2004; Mann et al., 1984; Robertson & Joanisse, 2010; Smith et al., 1989; C. L. Stein et al., 1984; Wiseheart et al., 2009). Due to their syntactic complexity, these sentences have been considered as potentially interesting structures to be studied in both typical and atypical populations. Several studies carried out in the 1970s and early 1980s (see Guasti, 2002 for a review) showed that typically developing children have difficulties in comprehending RCs, even after 6 years of age. In particular, subject RCs (e.g. *The dog that t is chasing the cat*) are generally easier for children to comprehend than object RCs (e.g. *The dog that the lion is chasing t*). The deficits in the interpretation of RCs by children have been addressed by two types of theories. The first type explains children’s poor performance as the effect of the lack of adult competence: children do not have access to the recursive construction and process RCs as flat structures. The second type attributes children’s difficulties either to the

complexity of the structure or to the infelicity of the pragmatic condition in which RCs have been experimentally probed.

Stein and colleagues (1984) tested the comprehension of both subject and object RCs in reading disabled American children (aged 7-10) and age-matched controls. According to the previous literature, they found that all children made more errors interpreting object RCs than subject RCs. Moreover, they found that disabled readers performed at lower levels than controls, irrespectively of age, thus supporting a structural syntactic deficit.

Mann and colleagues (1984) also tested the comprehension of RCs in American poor and good readers, adding a task involving the repetition of the same sentences. In this study it was found that poor readers performed worse than good readers, in both comprehension and repetition tasks. The latter result was interpreted as a support of an immature development of processing strategies. In particular, in line with Shankweiler and Crain's '*processing limitation hypothesis*' (1986), the authors concluded that poor readers failed in the repetition of RCs because of an ineffective use of phonemic representation in the service of working memory. However, they did not measure WM directly.

In a follow-up study by Smith and colleagues (1989), the verbal WM load imposed by relative clauses repetition was decreased by using a 'felicitous context', providing participants with toys to represent thematic role assignment. Using the same sentences used by Mann and colleagues (1984), they tested second grade poor readers and age matched controls, finding no significant group differences. Based on this result, they supported the conclusion of Mann and colleagues (1984), positing that the difficulty children with DD demonstrate in repeating RCs is a function of decreased verbal WM capacity rather than syntactic processing ability.

Similar conclusions were reached by Barshalom and colleagues (1993). In their study, they tested the comprehension and production of RCs in second grade poor readers and age-matched controls. Their results specifically showed that poor readers produced fewer relative clauses with object movement (e.g. [*the cat that the monkey scratched t*] *climbed up the tree*) compared to control children. According to the authors, the difficulty faced by poor readers with object RCs is caused by a processing issues. In order to be processed, object RCs require more working memory resources, and this additional need makes parsing more demanding.

Production and comprehension of **passive sentences** have been also extensively studied in individuals with DD (Leikin & Assayag-Bouskila, 2004; Reggiani, 2009; Robertson & Joanisse, 2010; C. L. Stein et al., 1984; Wiseheart et al., 2009). The particularity of passive constructions (e.g. *Horace was scratched by Alladin*) is the reorganisation of the grammatical functions found in the active sentences (e.g. *Alladin scratched Horace*): the object of the active verb becomes the

subject of the passive sentence (through an A-movement), while the subject of the active sentence is optionally expressed in a prepositional phrase in the passive sentence (Guasti, 2002).

Stein and colleagues (1984) investigated the interpretation of passive sentences in dyslexic children (aged 7-9) and age-matched controls, using a comprehension task involving active and passive sentences (both reversible and non-reversible passive sentences). Although dyslexic children made more errors with passive sentences relative to controls, the difference between the groups was not significant. This result led the authors to conclude that dyslexic children have a competent use of the passive construction.

Recently, different findings supporting the presence of a delay in the acquisition of passive in children with DD have been found by Reggiani (2009). Italian dyslexic children (mean age 9.7) were presented with passive sentences, including reversible and non-reversible sentences, as well as actional and non-actional sentences. By comparing the dyslexic children with aged-matched controls and younger controls (mean age 5.8) in a picture matching task, Reggiani obtained results supporting a maturational delay in dyslexic children, whose performance was more similar to that of younger controls, than to that of aged-matched controls.

Comprehension of **pronouns** and acquisition of **binding principles** have been also investigated in children with DD (Waltzman & Cairns, 2000). The binding theory deals with some aspects of the anaphoric relations holding between nominal and pronominal expression in sentences, consisting of several constraints (Guasti, 2002). It has been found that typically developing children generally master the binding principles around age 3-4, with the exception of certain aspects of the interpretation of non-reflexive pronouns that are not adult-like until the age of 6.

Waltzman and Cairns (2000) tested the interpretation of pronominal expressions in good and poor readers (mean age 8.75). By means of a picture selection task they showed that poor readers made significantly more errors with the interpretation of pronouns in some sentence contexts (e.g. *Pigi is drying her_i*) suggesting problems with binding principles. However, this result has not been replicated in a series of experiments conducted on Italian and Dutch dyslexic children (Fiorin, 2010). In these studies, the interpretive preferences of pronouns (bound vs. referential interpretation) were investigated (in sentences like *Every friend of Francesco painted his bike*), showing that dyslexic children did not differ from age-matched controls in their preference for the bound interpretation.

Recent studies generally addressed the question of **syntactic complexity** in individuals with DD using different syntactic structures (Leikin & Assayag-Bouskila, 2004; Robertson & Joanisse, 2010; Wiseheart et al., 2009). Leikin and Assayag-Bouskila (2004) tested syntactic complexity in Hebrew

speaking dyslexic children (aged 10-11) and age-matched controls. They tested five syntactic structures differing with respect to syntactic complexity (active, passive, conjoined, object-subject relative, subject-object relative) by using three different tasks differing according to the required level of activity (sentence-picture matching task, syntactic judgement task, sentence correction task). The results showed that the difficulties of dyslexic children increased passing from tasks requiring a low activity level to tasks requiring high activity level. Apart from that, the results indicated that dyslexic children were less accurate and slower than controls concerning all syntactic structures. Based on these results they concluded that the syntactic competence of dyslexic readers is not different from that of controls, but that the sentence comprehension difficulties are due to a processing deficit depending on a variety of factors, including phonological processing and memory resources.

The role of syntax and WM load in sentence comprehension has been further investigated in children with DD (Robertson & Joanisse, 2010). The authors used a sentence-picture matching task, manipulating the syntactic complexity of the sentences (canonical vs. noncanonical word order) as well as the sentence length (varied by adding adjectival information). Additionally, the task was administered in three conditions of increasing WM load (depending on the delay between the presentation of the sentences and the pictures). The results showed a general decreased performance in sentence comprehension as the WM load increased, that was more pronounced in the dyslexic group compared to the age-matched group. This finding, together with the significant correlation observed between phonological Short-Term Memory (STM, assessed through non-word repetition) and sentence comprehension performance under demanding WM loads, indicate that sentence processing difficulties in dyslexia might be explained as resulting from phonological STM limitations.

A similar study has been conducted by Wiseheart and colleagues (2009) on adults with DD. Through a sentence matching task, they tested the written comprehension of passive sentences (vs. active sentences) and of relative clauses (subject relatives vs. object relatives), in two positions (center-embedded vs. right-branching). Compared to controls, individuals with DD were significantly less accurate and marginally slower on passive sentences, while they were less accurate but did not differ in response times for sentences containing relative clauses. Interestingly, entering WM and word reading as covariates eliminated group differences, showing that syntactic deficits in adults with DD are constrained by both WM and word-reading ability.

1.2.2.2.2 Inflectional morphology

Recent studies addressed the **production of inflectional morphology** in children with DD. (Altmann et al., 2008; Joanisse et al., 2000). Joanisse and colleagues (2000) compared speech

perception-, phonological- and morphological skills in dyslexic children (aged around 8) and found that dyslexic children experienced difficulties with inflectional morphology, and particularly with the formation of past tense verbs. Similarly to the '*processing limitation hypothesis*' introduced to explain the deficit in comprehension and production of complex syntactic structures (Shankweiler & Crain, 1986), Joanisse and colleagues (2000) attribute these morphosyntactic problems to their phonological impairment. The nature of the phonological impairment that, according to Joanisse, adversely influenced the ability to acquire morphological patterns is however different to that previously reported (mainly a deficit in short-term memory or working memory). Formation of the past tense in English implies an important phonological component: Based on the stem of the verb, the past tense regular inflectional morpheme '-ed' can be pronounced /d/ (e.g. tugged), /t/ (e.g. baked) or /ɪd/ (e.g. patted). A phonological segmental deficit can affect the acquisition of these morphological patterns, mainly affecting their generalisation. The hypothesised relation between phonological skills and automatising of morphological paradigms furthermore implies that the phonological impairment has a strong impact on generating regular-like past tenses (Joanisse, 2004).

Results in line with a more general deficit in inflectional morphology have been found by Altmann and colleagues (2008), who compared dyslexic individuals (N = 13, age range: 8-22) and control participants in a sentence production task. Starting from three-word stimuli including a verb and two nouns (e.g. Candy – Hidden – Mary), participants were asked to produce sentences including all the words without changing the form. The experimental conditions included three types of verb stimuli: agent-patient verbs with regular morphology (used as control stimuli), agent-patient verbs with irregular morphology (requiring the explicit awareness of the grammatical constraints inherent the morphological form) and theme-experience verbs with regular morphology (requiring the lexical-syntactic knowledge about the argument structure of these verbs). The results showed that students with DD produced more dysfluent, ungrammatical and incomplete responses than typical readers, particularly when using irregular past participles. These results were generally discussed as revealing subtle residual syntactic deficits in older participants, although the restricted number of participants (only 6 dyslexic participants older than 14.4) did not allow the authors to any strong claim.

Other studies focused on dyslexics' **morphosyntactic skills in comprehension** (Jiménez et al., 2004; Rispens & Been, 2007; Robertson & Joanisse, 2010) underling the relationship between phonological and morphosyntactic skills. In line with conceptualisations related to the '*processing limitation hypothesis*' (Shankweiler & Crain, 1986), WM load and STM (assessed by non-word repetition) were operationalised as phonological variables. Jiménez and colleagues (2004),

examined the differences between children with and without DD in various (morpho)syntactic tasks (including number and gender agreement, grammatical structure and function words tasks) controlling for WM or not (listening span test). Their results suggest that deficits in (morpho)syntactic processing are determined by deficits in phonological processing, since dyslexic children have more difficulty in the phonologically more demanding tasks, consisting in gender and number agreement processing tasks, also when controlling for WM.

Rispens and colleagues (2004) specifically addressed the sensibility to subject-verb agreement in Dutch children with DD (aged 8-10), compared to two groups of control children matched for chronological age and reading level. An auditory grammaticality judgement Task tested the ability to distinguish between correct vs. incorrect subject-verb agreement. In particular, three types of subject-verb agreement violations were used, linking a singular noun subject to either a verb inflected for the first person singular (type 1) or for plural (type 2) and linking a plural noun subject to a verb inflected for the third person singular (type 3).

- Type 1: de rare clown (3rd singular) *maak (1st singular)/maakt een grapje
(*the funny clown *make/makes a joke*)
- Type 2: de rare clown (3rd singular) *maaken (3rd plural)/maakt een grapje
- Type 3: de rare clowns (3rd plural) *maakt (3rd singular)/maakt een grapje

Dyslexic children scored significantly worse than age matched controls in judging all three types. Additionally, they were outperformed by reading level matched controls: this constitutes an additional proof that less exposure to reading and the low reading ability are not a cause of the morphosyntactic problems of dyslexic children. The same sentences and paradigm were used in a follow-up study (Rispens & Been, 2007) conducted on dyslexic children of the same age. The differences between dyslexic children and age-matched controls were confirmed. In addition, sensitivity to subject-verb agreement was found to be strongly correlated with STM measures (non-word repetition). Based on this result, the authors concluded that the morphosyntactic deficits might be explained as resulting from phonological STM limitations.

Interestingly, Leikin and Hagit (2006) investigated morphological processing in Hebrew adults with DD, finding interesting results supporting the independence of morphological awareness weakness and phonological processing deficits in their dyslexic participants. Specifically, they used a masked-prime paradigm to test the 'morphological knowledge', and particularly the benefit provided by the primed presentation of words sharing both pattern and root morphemes in lexical decision. The results showed that, although generally slower, dyslexic readers were relatively more sensitive to roots and verb patterns as separate morphemes than controls. This result of a normal morphological knowledge in dyslexic reader is however in contrast with the general results of a

morphological awareness deficit, as tested by morphological production and inflection of words and pseudowords and by morphological relations judgement. These contrasting results led the authors to conclude that the explanation should probably be sought in a general metalinguistic processing deficiency. In addition, given the independent contribution of phonological and morphological awareness to reading skills, the authors also exclude the possibility that the weakness in morphological awareness can be based on phonological deficits.

1.2.3 Other high-linguistic deficits in DD

There is a limited number of behavioural studies that have focused on other high-linguistic skills in DD. In particular, **vocabulary development** in children at-risk for DD has been extensively investigated. In her already cited longitudinal study, Scarborough (1990) followed children at genetic risk for DD from the age of 30 months, measuring receptive and productive vocabulary using the Peabody Picture vocabulary test (Dunn & Dunn, 1981) and the Boston Naming test (Kaplan, Goodglass, & Weintraub, 1983). Although the vocabulary development of at-risk children did not differ from the one of the age-matched control children at 30 months of age, differences between groups were found at 42 months, with at-risk children performing significantly lower on both tests. Similarly, Lyytinen and colleagues (2001) found that at 24 months of age children at familiar risk for DD did not differ from age-matched controls in vocabulary production, while differences were found at 42 months. These findings suggest that the impairment in lexical development is more likely to be interpreted as a secondary impairment rather than a primary impairment. In particular, it might be caused by deficits in phonology or in the development of syntax.

Semantic skills have been sporadically investigated in individuals with DD. Typically, **semantic representations** are thought to be intact in children with DD: during reading tasks they rely more on semantic context in word identification. This is shown by studies contrasting word identification performance in context vs. out of context, where children with DD show larger context effects than typical readers in terms of both speed and accuracy (e.g., Nation & Snowling, 1998). Other researchers, however, hypothesise semantic deficits in children with DD because “*it makes sense that the same factors that produced weaker phonological and orthographic representations in these children could very well have also produced weaker semantic representations*” (Betjemann & Keenan, 2008). Support for the possibility of deficits in semantic representations in children with DD comes from the finding that they show reduced performances in both reading and listening comprehension. Batjemann and Keenan (2008), recently assessed lexical priming in children with DD and in age-matched controls, in visual and auditory lexical decision tasks. In both modalities,

children with DD were found to have deficits in semantic, phonological/graphemic and combined priming. The authors conclude that these semantic deficits may contribute to both word reading and comprehension problems seen in children with DD.

Finally, a pilot study (Griffiths, 2007) has investigated **pragmatic abilities** in a sample of adults (aged 17 to 41 years) with and without DD. In this study, the Right Hemisphere Language Battery has been administered, to investigate dyslexics' abilities in understanding metaphors and humour, and in extracting inferential information from stories. The results generally showed more mistakes in dyslexic participants than in controls, thus preliminary supporting the existence of deficits in this area, as also shown by a self-reported questionnaire used to estimate pragmatic competence. As conclusion, the author underlies the possibility that the pragmatic impairment may be due to deficits in working memory, processing and automatization.

1.3 Comparing Developmental Dyslexia to Specific Language Impairment

As reviewed in the previous section, linguistic deficits have often been reported in individuals with DD, as well as children at risk for the disorder. These linguistic deficits involve not only phonology, but also morphosyntax and syntax, and partially also semantics and pragmatics. The growing awareness of the presence of these impairments in DD has increased the interest on the overlap with Specific Language Impairment (SLI), defined as a specific disorder in acquiring language, despite normal non-linguistic development (Bishop & Snowling, 2004; Catts, Adlof, Hogan, & Weismer, 2005; McArthur, Hogben, Edwards, Heath, & Mengler, 2000).

In the following sections, I will provide a general introduction to SLI. The overlap between DD and SLI will be thus described, particularly referring to theories and recent evidence.

1.3.1 General introduction on SLI

Specific Language Impairment (SLI) is a developmental disorder characterised by a discrepancy between verbal abilities and nonverbal abilities. Typically, both production and comprehension of language are affected. Leonard (1998) estimated that around 7% of children suffer of some forms of SLI, with males affected three times more frequently than females. However, the prevalence of SLI varies as a function of age. Longitudinal studies show that only 56% to 73% of preschool children diagnosed as SLI continue to show symptoms of impairment up to adulthood (e.g., Johnson et al.,

1999). Additionally, it is important to remember that the prevalence of the disorder can also vary as a function of the criteria used to define SLI, and of the tests used to assess linguistic difficulties (see Leonard, 1998 for an extensive review). Another major characteristic of SLI is the large variability, within and across individuals, and across languages.

The aetiology of SLI is still not known. Several studies have observed a familiar aggregation, showing a higher prevalence of individuals with language-related disorders in the family of a child with SLI than in the family of a child without SLI (Rice, Haney, & Wexler, 1998; Tomblin, 1989), suggesting that SLI has a genetic basis.

Language impairments in children with SLI can range from impairments in phonological abilities to pragmatic abilities with everything in between (morphological abilities, morphosyntactic abilities, lexical-semantic abilities and syntactic abilities). Despite this wide range of difficulties, SLI is often characterised in terms of **deficits in grammar**. Many researchers focus their research primarily on SLI children suffering from grammatical deficits, and some even refer to the relevant type of SLI as G(rammatical)-SLI (e.g., van der Lely, 2005b). Within the grammatical domain, several deficits have been reported in SLI children, particularly concerning argument structure, inflectional morphology and morphosyntax, and syntactic structure (Leonard, 1998). Italian-speaking children with SLI, for example, normally use shorter sentences with respect to their peers with typical development. Many researches on grammatical production have revealed limited use of function words such as articles and clitics (Cipriani et al., 1991; Sabbadini, Volterra, Leonard, & Campagnoli, 1987). More recently, Bortolini and colleagues (2006) identified third-person plural inflection, direct-object clitics (as well as non-word repetition) as clinical markers for SLI in Italian, with direct-object clitics and non-word repetition showing the highest sensitivity and specificity.

In addition to grammatical deficits, **poor phonological processing** has also been extensively demonstrated in children with SLI. In particular, as already reported for Bortolini et al.'s study (2006), difficulties with non-word repetition is a strong clinical marker of language impairment (see also Botting & Conti-Ramsden, 2001; Conti-Ramsden & Hesketh, 2003)⁴. This deficit has been interpreted as indicating a limitation in the phonological short-term memory system that is important for learning new vocabulary (Gathercole & Baddeley, 1990b) and syntax (Gathercole & Baddeley, 1990a). In addition, deficits in other areas of the phonological domain, namely phonological awareness, have been reported both in children with SLI (Carroll & Snowling, 2004) and adolescents with a history of SLI (Snowling, Bishop, & Stothard, 2000), although children with both language and reading impairment have been found to perform most poorly as far as these skills are concerned (Brizzolara et al., 2006; Fraser, Goswami, & Conti-Ramsden, 2010; Nithart et al.,

⁴ However, it should be noted that the phonological features of the language might play an important role. For example, Cantonese-Chinese-speaking preschool children with SLI have been found to perform as well as their age peers on non-word repetition.

2009). Interestingly, it should be noted that Tallal's *Auditory Temporal deficit hypothesis* (already described in Section 1.2.1.2), claiming that a deficit in the processing of rapidly changing acoustic tones leads to difficulties in the perception of the phonemes, and thus to phonological impairment, was originally proposed to explain SLI linguistic deficits (Tallal & Piercy, 1973). Several studies, in fact, have shown that SLI children are often characterised by deficits concerning speech as well as concerning non-speech auditory perception (see Corriveau, Pasquini, & Goswami, 2007 for a recent review).

The origin of the grammatical and phonological deficits in SLI is still the object of a wide ranging debate. Theories have specifically focused on the origin of grammatical deficits. In particular, two main accounts are given. On the one hand, linguistically oriented scholars argued that SLI is a *modular deficit*, affecting only linguistic abilities, and particularly the syntactic module of language (Clahsen, 1989; Gopnik, Dalalakis, Fukuda, & Fukuda, 1997; Rice, Wexler, & Cleave, 1995; van der Lely, 2005a). On the other hand, *non-modular accounts* attribute the deficit to a general underlying information processing deficits (Gathercole & Baddeley, 1990a) or more specifically to a weakness of the perceptual system, which causes difficulties in the perception of phonologically non-salient morphemes (Leonard, 1998).

Within the **modular account**, the *Extended Optional Infinitive Account* (Rice et al., 1995) postulates that children with SLI use optional (or root) infinitives for an extended period of time. They produce sentences in which the tense feature is absent and consequently the morphemes expressing this feature are not realised. This results from a delay in the acquisition of a specific property, i.e., the obligatory requirement of marking tense in each main clause.

The *Agreement Missing Hypothesis* (Clahsen, 1989) explains the deficits in inflectional morphemes reported by SLI children as a specific deficit in establishing a relationship of grammatical agreement between two elements. Empirical evidence for this hypothesis comes from a study on German- and English-speaking SLI children, demonstrating greater difficulties in marking number agreement than in marking tense agreement in verbs (Clahsen, Bartke, & Göllner, 1997).

A third specific hypothesis within the general modular account is the *Representational Deficit for Dependent Relations* (van der Lely, 2005a). According to van der Lely, SLI consists in a deficit in computing grammatical operations involving a structural dependency between two different constituents. Examples of structural dependencies are the agreement of a verb with its subject, the syntactic relation between a reflexive or a pronoun with its antecedent (binding principles) or more generally the relationships involved in syntactic movements (as in object who-questions like '*who did Mrs Peacock see in the lounge?*', where *who* is the object of the verb *see*).

Finally, Gopnick and collaborators proposed another account, describing SLI as a *Grammar Lacking Grammatical Inflectional Features* (Gopnik et al., 1997). According to this hypothesis, SLI

children cannot construct implicit rules governing morphological and phonological processes in grammar. While typically developing children can abstract rules from the language input, SLI children cannot understand the internal structure of inflected words, and are not able to build implicit rules for handling inflectional morphology. They preferentially use the lexical storage-associative system and, for this reason, they do not show the normal regularity advantage, perform similarly on regular and irregular past-tense marking and manifest similar frequency effects for regular and irregular verbs (Ullman & Gopnik, 1999; van der Lely & Ullman, 2001).

Within the **non-modular account**, the *Surface Hypothesis* focuses on the physical properties of the grammatical morphemes. Leonard and colleagues (Leonard, Eyer, Bedore, & Grela, 1997) pointed out that SLI children's typical difficulties in the production and comprehension of some morphemes (e.g., consonant inflections or weak-syllable morphemes) could have their basis in the acoustical processing of the input, particularly in the difficulty to perceive short and rapid sounds such as some verbal and nominal inflections (Leonard, 1998). Extensive cross-linguistic research has revealed that particular grammatical categories are more affected in some languages than in others (see Leonard, 1998). For example, Italian-speaking children with SLI do not show the disproportionate difficulty with tense marking, which is, however, observed in their English-speaking peers (Bortolini, Caselli, & Leonard, 1997). It seems that the phonological properties of the grammatical category are responsible for these cross-linguistic differences: the same grammatical category is easier to perceive in a language in which it is stressed or syllabic, and therefore of longer duration, than in a language in which it is pre-stressed or sub-syllabic, and therefore of shorter duration.

More generally, Gathercole and Baddeley (1990a), and more recently Montgomery (2003), proposed a *limited processing account*. According to this model, SLI develops out of a limited capacity for processing and storage information, where the already described deficits in either verbal short-memory or working memory play a central role, as far as sentence comprehension is concerned.

As emerged from this brief summary of the theories proposed to explain grammatical deficits in SLI individuals, it is evident that the nature of these impairments is not clear yet. Similarly to what is reported concerning the literature on DD, grammatical skills are hypothesised to be due to a specific linguistic deficit, or to an underlying phonological deficit (in turns concerning phonological processing and STM/WM). Within this debate, another comprehensive theory, named *mapping theory*, has been recently proposed by Chiat (2001). According to this author, the impaired phonological processing in SLI leads to the disruption of mapping processes, considered as *sine qua non* of language acquisition. Mapping processes contribute not only to the segmentation and representation of lexical phonology, but have wide-ranging consequences for syntactic

development. For example, the discovery that past tense is marked in English, is only possible if the phonological variation in familiar form-meaning pairs is detected (i.e., *walk vs. walked*). Similarly, even the most primitive syntactic combinations require children to recognise substantial prosodic chunks and phonological details.

1.3.2 Theories and evidence on the overlap between DD and SLI

This brief review of the cognitive deficits mainly reported in individuals with DD and SLI has shown that these two disorders share common difficulties, mainly in the linguistic sphere. We have already seen (Section 1.2.1) that a **phonological processing deficit** preventing the construction storage and access to phonological representations is considered the core deficit for DD. From the angle of SLI, it has also been proposed that a phonological impairment is the primary cause of SLI and impacts on higher level language skills, such as lexical and syntactic abilities (see Section 1.3.1). A similar argument can be provided for **non-phonological linguistic deficits**, and mainly concerning the domain of (morpho)syntax. We have seen that, despite the wide range of difficulties shown by SLI children, this disorder has often been characterised in terms of deficits with grammar. In Section 1.3.1. I have, in fact, reviewed the range of theories focusing on syntactic difficulties, considered as the core features of SLI. The less obvious evidence, that I have however strongly underlined in the present chapter, is that also dyslexic individuals have been found to perform worse than typically developing children in a wide range of tasks tapping linguistic skills different from phonology. In particular, in the domain of (morpho)syntax, the comprehension and production of syntactic complex structures as well as inflectional morphology often resulted impaired in DD individuals (see Section 1.2.2).

Further investigations have additionally focused on the reading outcome in SLI and late-talking children (Botting, Simkin, & Conti-Ramsden, 2006; Rescorla, 2005; Snowling et al., 2000). It is clear that the acquisition of phonology, and more generally of linguistic skills, has a strong impact on the acquisition of reading (written language). Due to this relationship, it could be expected that at least some children affected by SLI in preschool age, and particularly those more impaired in phonological skills, should develop additional problems in learning to read. As expected, reading, and in particular reading comprehension, was often found to be impaired in SLI children (Botting et al., 2006; Rescorla, 2005; Snowling et al., 2000). For example it was impaired in 80% of Botting et al.'s sample, constituted by children with a previous language impairment.

In addition to studies on the common cognitive deficits shared by DD and SLI, evidence for an overlap derives from studies on the clinical comorbidity between disorders. All epidemiological studies and studies conducted on referred clinical sample that have been carried out on DD and SLI

populations (including speech sound disorder as well) have been recently reviewed by Pennington and Bishop (2009). Generally, the results confirm the presence of a “genuine comorbidity” among the disorders, due to the fact that each clinical sample had a significantly greater probability than chance to show an additional diagnosis (Catts, 1993, 1995; Flax et al., 2003; McArthur et al., 2000). In other words, many children with DD also meet criteria for SLI, and many children with SLI also meet criteria for DD. For example, McArthur and colleagues (2000) found that 55% of the children with DD scored more than one standard deviation below the average on a standardised test measuring a range of syntactic and semantic oral language abilities (CELF-R). Similarly, Catts and colleagues found that around 50% of the language impaired children in their sample, also had difficulties with reading (scoring one standard deviation below the norm on word and pseudo-word reading tasks), and 20% of these children scored two standard deviations below the average (Catts, 1993, 1995)⁵.

The occurrence of oral language impairments in DD and of reading difficulties in SLI have led some theorists to propose different models to explain the relationship between DD and SLI. Figure 1.1 graphically presents the three main model.

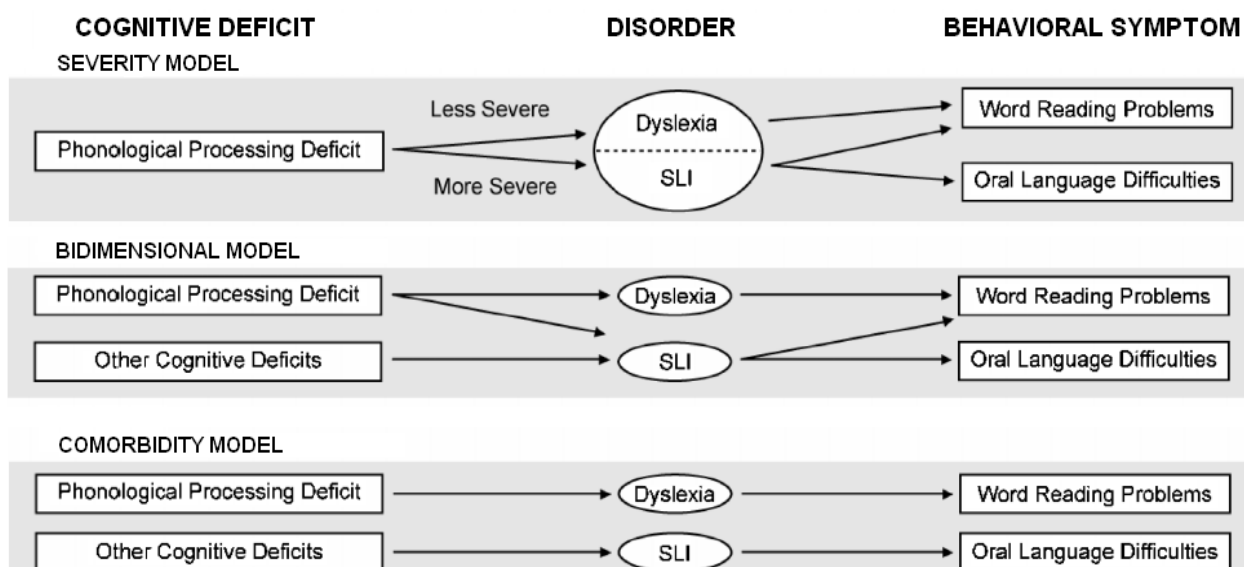


Figure 1.1: Models of the relationship between Dyslexia and SLI. Based on Catts et al. (2005)

The oldest model proposed that DD and SLI are different manifestations of the same underlying cognitive deficit, i.e., a phonological processing deficit (Kahmi & Catts, 1986; Tallal, Allard, Miller, & Curtiss, 1997), or a more basic auditory processing impairment leading to the phonological impairment (see Tallal, 2004 for a review). According to this model, named *severity model*, DD and SLI simply differ quantitatively along a dimension of severity, with mildly affected

⁵ Interestingly, the review conducted by Pennington and Bishop (2009), including also many unpublished works, additionally revealed that when SLI appeared in comorbidity with speech sound disorder, the probability to later develop also DD greatly increased.

individuals developing reading impairment only, and more severely affected individuals developing a mixed DD plus SLI profile. As a natural consequence of this model, the presence of language impairment without reading deficit is unlikely to exist. However, the very recent scientific literature is full of studies that have described this particularly sample (i.e., Fraser et al., 2010; Rispens & Parigger, 2010), culminating in a paper by Bishop, McDonald, Bird, and Hayiou-Thomas (2009) titled “*Children who read words accurately despite language impairment: who are they and how do they do it?*”.

More recently, Bishop and Snowling (2004) have proposed a *bidimensional model*, including an additional dimension, orthogonal to phonology, concerning non-phonological language (encapsulating semantic, syntactic and discourse domains). According to this model, the two dimensions (phonological and non-phonological) vary independently (see also Figure 1.2). Children with impairments limited to the phonological domain would have DD, while children with deficits in both phonological and non-phonological domains would be diagnosed with SLI. According to this model, SLI differs from DD in the way it involves an additional cognitive deficit or deficits, which operates independently from the phonological processing deficit and causes problems in the development of oral language. This model, however, does not provide an explanation for the presence of non-phonological deficits in DD, as reviewed in Section 1.2.2.

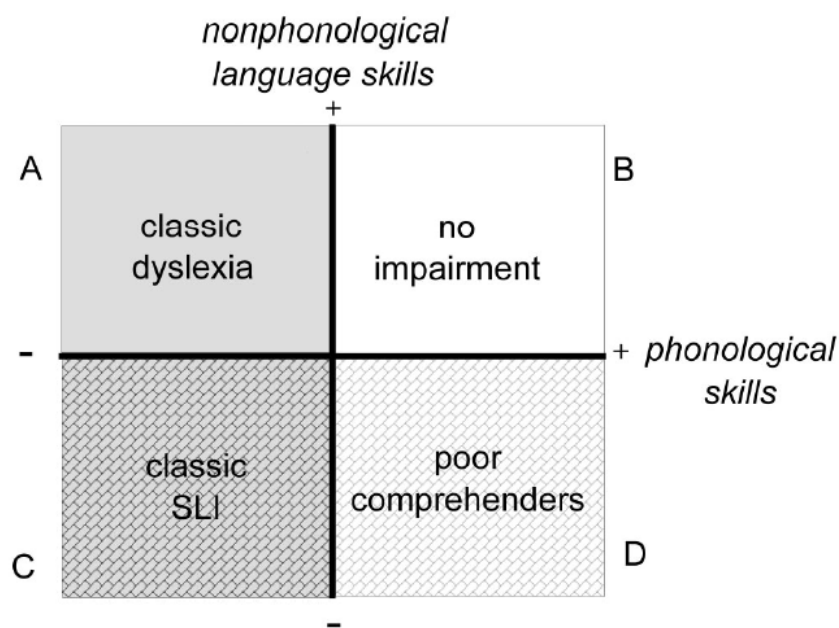


Figure 1.2: A schematic representation of the two-dimensional model describing the relationship between SLI and DD (Bishop & Snowling, 2004, p. 859)

A third model, named *comorbidity model* (Catts et al., 2005), asserts that DD and SLI are distinct disorders, with different cognitive deficits and different behavioural manifestations. The overlap is due to comorbidity: although the disorders are distinct, they are related and sometimes occur together in the same individual. As shown in Figure 1.1, a phonological processing deficit is the

core deficit in DD, while SLI children only show oral language deficits. Phonological processing deficits thus underlie SLI only for those SLI individuals who have both DD and SLI.

At the present time, in light of recent studies that have studied samples of children affected by DD and/or SLI, in an attempt to provide a characterisation at cognitive levels (Bishop et al., 2009; Brizzolara et al., 2006; Chilosi et al., 2009; De Bree, 2007; Fraser et al., 2010; Joanisse et al., 2000; Lami, Palmieri, Solimando, & Pizzoli, 2009; Nithart et al., 2009; Rispens, 2004; Rispens & Been, 2007; Robertson & Joanisse, 2010; Scuccimarra et al., 2008; Wilsenach, 2006), the three models described above seems simplistic. Pennington and Bishop (2009) proposed a *multiple overlapping risk factor* model, in opposition to single deficit approaches to developmental disorders (Pennington, 2006). Single source models (namely the severity model) cannot predict the wide heterogeneity of the two disorders. According to Pennington and Bishop's model, DD and SLI are complex and multifactorial disorders, in terms of their genetic and environmental etiology, as well as their cognitive underpinnings. Each disorder arises as the consequence of a specific constellation of underlying deficits, and from multiple risks and protective factors. Under this view, comorbidity results from some of these risk factors being shared by different disorders. Both the comorbidity model (Catts et al., 2005) and the bidimensional model (Bishop & Snowling, 2004) appear thus revised, in light of a more complex model predicting the presence of more than two cognitive deficits underlying both DD and SLI, that combine in order to obtain different profiles in the behavioural manifestation.

1.4 General research questions

As we have seen in this introduction, two principle approaches have been used to investigate the linguistic nature of DD. On the one hand the assessment of dyslexic individuals' linguistic skills in a broader perspective (beyond the domain of phonology) and with sensitive measures can provide a window on the generally poor linguistic skills characterising DD. On the other hand the investigation of the relationship and the overlap with SLI, considered as the developmental disorder typically characterised by deficits in the broader linguistic sphere, can confirm that the border between the two disorders is not completely defined, and that they share several common cognitive deficits. Although these two approaches are intrinsically linked, they highlight two interesting issues that need further investigation and that are addressed on a general scale in the present dissertation.

a) Is DD characterised by linguistic deficits, mainly involving the morphosyntactic domain?

This question is the main point of the dissertation and has been addressed in three studies involving different dyslexic populations, namely Italian dyslexic adults and children, and German dyslexic adults. In particular, different behavioural and electrophysiological measures (see next Chapter) were used, and an attempt to analyse the results within the neuropsychological and the linguistic framework will be provided.

b) Are the cognitive deficits underlying DD and SLI the same or different?

This question has been addressed in the study described in Chapter 4 where dyslexic children with and without SLI were compared in different phonological and morphosyntactic measures. The analysis of the neuropsychological and linguistic profiles characterising the two clinical groups will provide a window on the nature of the overlap between the two disorders.

A third important issue that has been underlined in this introduction concerns the nature and the specificity of the (morpho)syntactic deficits in DD. As several authors argue, in concerns to both DD and SLI, the (morpho)syntactic impairment could be based on the underlying phonological deficit expressed as poor short-term working memory or a more general phonological processing deficit. Clarifying this issue constitutes an important theoretical goal, and is necessary in order to fully understand, as well, the previous issues.

c) Are the (morpho)syntactic deficits revealed in DD specific or based on an underlying phonological impairment?

This question has been addressed transversally in all the studies, by investigating the relationship between phonological and morphosyntactic measures. However, the study described in Chapter 5 provides an explicit manipulation of the morphosyntactic task in order to investigate the role of the acoustical salience of the inflections on the sensitivity to subject-verb agreement violations.

Chapter 2

Event-related potentials in the study of language and language-related impairments

2.1 From electroencephalography to Event-Related brain potentials

In 1929, the German psychiatrist Hans Berger gave a first report on the electroencephalogram (EEG), a non-invasive method used to measure the electrical voltage fluctuations of the human cortex via electrodes⁶ placed onto the scalp. The neural activity recorded in the EEG is largely generated by the pyramidal cells of the cortex, since the electrical activity produced in subcortical regions cannot be measured at the surface of the scalp. EEG recording represents nowadays a diagnostic instrument in the clinical practice, as well as an important tool for scientific purposes.

The recording positions of electrodes are standardised and defined by international guidelines, to ensure comparable cross-study reference. The most common electrode naming and placing procedure is the 10-20 system (Jasper, 1958), where electrodes are located at distances of 10% or 20% along the longitudinal line across the head (see Figure 2.1). Electrode positions are named using a combination of letters and numbers to indicate their proximity to underlying brain regions (F = frontal, C = central, T = temporal, P = parietal, O = occipital), and their laterality (odd numbers = left hemisphere, even numbers = right hemisphere, z = midline). In addition, numbers indicate the distance from the midline, with greater number indicating greater distance.

Generally, the EEG measures the differential potential between several active electrodes placed at sites of neuronal activity and one common inactive electrode placed at a site with no or only little brain activity, serving as reference⁷ (in Figure 2.1, A1 and A2, located at mastoids). The ongoing voltage changes captured by the electrodes are amplified, sampled (usually at 250, 500 or 1000 Hz), and finally stored on a computer for further processing (for a complete description of these processes see Handy, 2005; Luck, 2005).

⁶ Electrodes normally consist of sensors made of metal. The most suitable metals are platinum, gold, silver, or silver chloride (Ag/AgCl).

⁷ Here we refer to the general *monopolar montage*, also called *common reference method*. It is opposed to the *bipolar montage*, where all electrodes are connected together in chains.

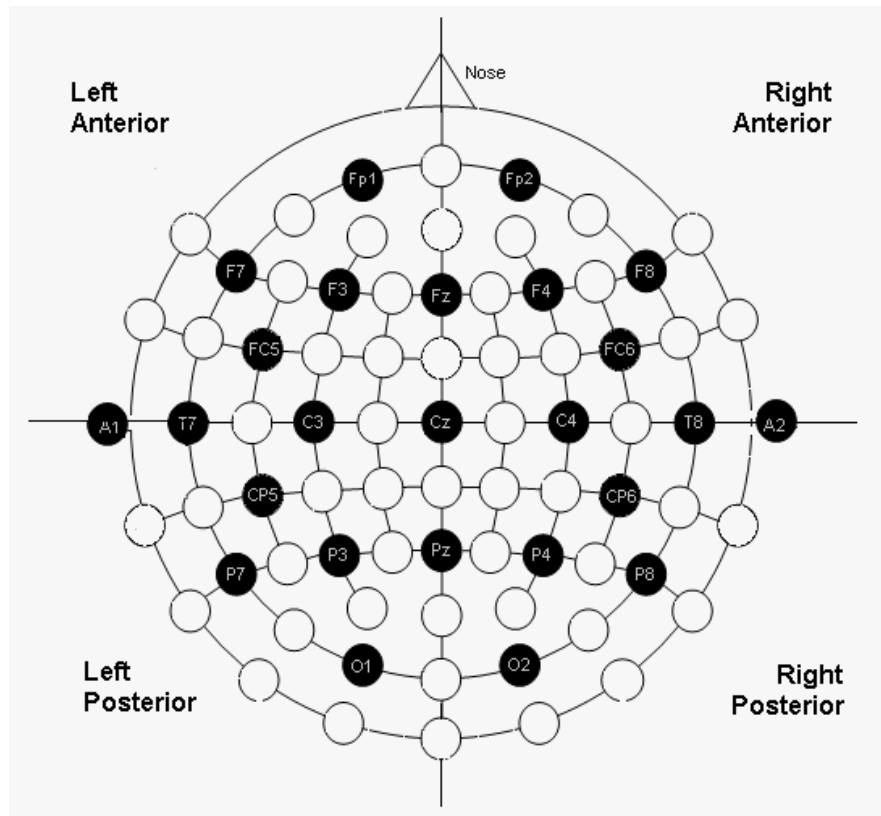


Figure 2.1 Electrode positions according to the International 10-20 system(Jasper, 1958). Channels employed in the present dissertation (although with differences across studies) are shaded in black.

In neuroscience, researchers are mostly interested in voltage fluctuations that are time-locked to specific sensory or motor events, named Event-Related Potentials (ERPs), as it is generally assumed that they reflect cognitive processes related to the event. The detection of those evoked responses in the global EEG signal is however complex, since they are relatively small and superimposed to basal electroencephalographic activity that has larger amplitude. For example, the amplitude of the effects typically induced by linguistic manipulations is in the order of a few μV , while background EEG activity (such as ocular, muscular and cardiac artifacts) is generally up to $100 \mu\text{V}$. Therefore, signal processing procedures are necessary to improve the Signal-to-Noise ratio and extract the event-related signal from the uncorrelated noise. The *averaging technique* involves the repeated presentation of physically or conceptually identical stimuli, and is based on the assumption that the underlying mental process remains equal across several stimuli of the same type while background activity is random. The ideal number of trials within one experiment depends on the size of the signal one is attempting to record and the noise level of the data. Figure 2.2 illustrates the averaging procedure for epoch extraction, and the subsequent prototypical ERP components obtained in response to the auditory presentation of short tones⁸.

⁸ What we see here is the average of several events in a single subjects. Data are usually data are presented in *Grand Average ERP* waveforms, including several single-subject averages.

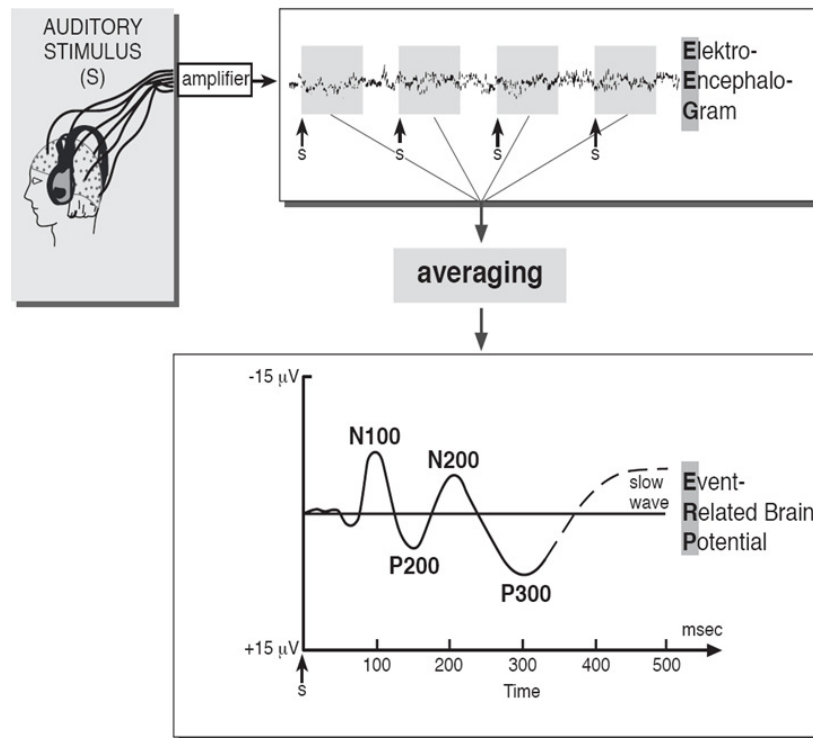


Figure 2.2: From EEG to ERP. Averaging procedure resulting in a typical auditory ERP waveform.

Negativity is plotted upwards by convention.

The obtained ERP consists in a series of positive and negative deflections over time that are usually referred to as components. As can be seen at the bottom section of Figure 2.2, these are mainly characterised by *latency* (expressed in ms and plotted on the x-axis), indicating the point in time at which the ERP component occurs relative to the stimulus onset and *amplitude* (expressed in μV and plotted on the y-axis), reflecting the size of the neural activity generated in response to an experimental stimulus. Based on the ERP component that is under observation, the decrease of the amplitude may be related to a reduction in the processing demands or to the efficiency of that cognitive process. The amplitude of ERPs components is always measured in relation to a baseline, constituted by the EEG signal preceding the stimulus-onset (usually lasting 100 ms), where the mean amplitude is set to zero. In addition, the *polarity* (negative vs. positive) of the component depends on the pole orientation of the measured electric field. Both polarity and peak latency contribute to the nomenclature of the ERP components. Thus an N100 is a negativity peaking at 100 ms after stimulus onset, whereas a P200 is a positivity usually peaking at a latency of 200 ms. Additionally, the *scalp distribution or topography* of an ERP component refers to the position on the scalp where the effect occurs. The nomenclature of some ERP component also depends on this feature, for example the *Left Anterior Negativity (LAN)*, is a negative component observed at left anterior sites (see Figure 2.1). One has to be aware that the activity measured at a certain position on the scalp does not necessarily originate from the brain structures directly underlying that site,

and that specific source localisation techniques should be used in order to estimate the loci of neural activity (Handy, 2005). However, the topography of ERPs can provide evidence about differences between experimental conditions.

ERP components are divided into two major classes: *exogenous* or stimulus-driven components, occurring up to 80 ms after stimulus onset and reflecting the obligatory brain responses, and *endogenous* components, which have later onsets and are regarded as indicators of higher-order cognitive processing, as they are clearly influenced by task demands, amount of attention required or expectancies of the participants. These latter components are of major interest in any ERP investigation in cognitive processes.

The next section will introduce some classical ERP components mainly associated with language processing, along with their prevalent functional interpretation. As exogenous components are not in the focus of the current thesis, they will be described very briefly, while a special emphasis will be directed towards the main endogenous components associated with language processing. In particular, the components associated with phonemic discrimination (MMN), prosodic processing (ERAN and CPS), phonological/semantic priming and lexical semantic processing (N400) and (morpho)syntactic processing (LAN and P600) will be described, with a particular focus on the components taken into account in the literature on DD and SLI (reviewed in Section 2.5). Finally, given the fact that a morphosyntactic violation paradigm (particularly concerning subject-verb number agreement violations) has been used in the experiments collected in the present dissertation, an additional section will specifically review the studies described in the literature concerning this specific ERP paradigm.

2.2 The main ERP components associated with language processing

N100/P200 components. The occurrence of any auditory or visual stimulus elicits an ERP pattern named N1-P2 complex (Näätänen & Picton, 1987) consisting of a negative deflection occurring at approximately 100 ms after stimulus onset, followed by a positive deflection at around 200 ms (see Figure 2.2). These endogenous components are associated with activity in primary sensory cortex, and are highly sensitive to the physical properties of the stimuli (e.g. loudness and fundamental frequency) but also to cognitive parameters such as selective attention (Näätänen & Picton, 1987).

Mismatch Negativity (MMN). The MMN, firstly described in 1978 (Näätänen, Gaillard, & Mäntysalo) is a fronto-central negativity (with reversed polarity at mastoids) occurring

approximately 100 ms after stimulus onset (see Figure 2.3). Although it has been extensively studied in the auditory modality, some attempts to identify an equivalent to the MMN in the visual modality have been reported (see Pazo-Alvarez, Cadaveira, & Amenedo, 2003 for a review). The auditory MMN is typically observed using auditory oddball paradigms, in which participants are presented with a sound sequence consisting of a frequently repeated standard stimulus that is occasionally and randomly replaced by a deviant stimulus, which differs in one or more physical features (such as pitch, duration, intensity, rise time). In addition to these acoustical changes, more complex and abstract features such as phonetic changes have been found to elicit the MMN (Kujala & Näätänen, 2001). The MMN response has thus been interpreted as the brain's detection of the deviant stimulus among the standard ones and is especially apparent in the subtraction wave (obtained by subtracting the ERP to the standard stimuli from the ERP to the deviant stimuli, see Figure 2.3). In addition, the MMN has been shown even in absence of attention allocation, suggesting that it reflects an automatic and implicit change detection mechanism (Näätänen, Paavilainen, Tiitinen, Jiang, & Alho, 1993). The fact that MMN can be elicited even in the absence of attention makes it a unique measure of auditory discrimination accuracy, particularly suitable for the investigation of change detection responses in children with limited attention and motivation (Kujala & Näätänen, 2001), as well as in early infancy (see Cheour, Leppänen, & Kraus, 2000 for a review).

Numerous experiments with (typical) adults suggest a good correspondence between the presence of the MMN and the discriminability between the standard and deviant stimuli (expressed as accuracy in discrimination behavioural tests), resulting in larger and earlier MMN responses when the physical difference between standard and deviant is larger (e.g. Amenedo & Escera, 2000). Given these premises, the role of the MMN component as index of discrimination between auditory stimuli is widely established. In addition, the evidence that it is harder to elicit when standards and deviants are presented in an oddball paradigm with long intervals (10 s or more) between stimuli (Sams, Hari, Rif, & Knuutila, 1993) suggests that the MMN reflects the operation of auditory sensory memory.

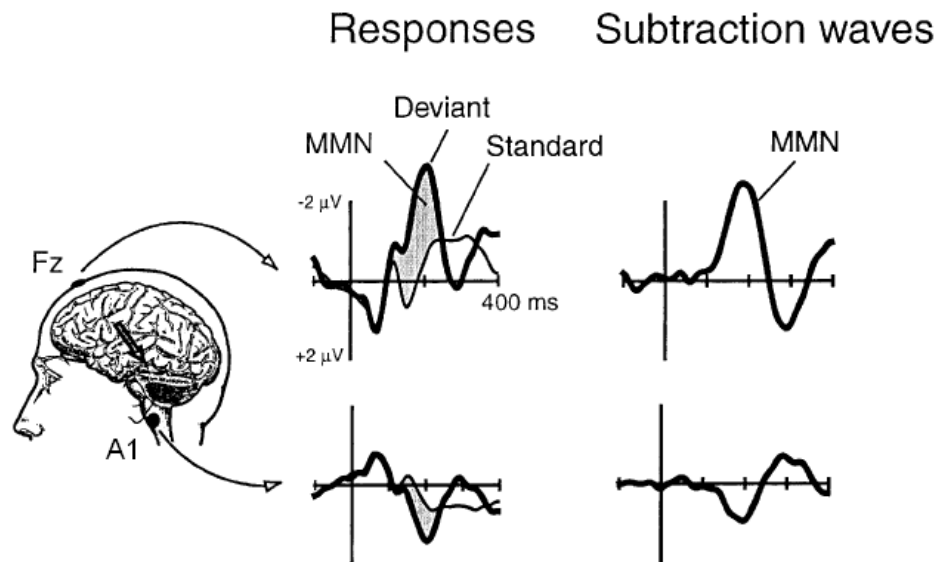


Figure 2.3: A schematic illustration of the MMN. The MMN is usually maximal at fronto-central sites (Fz, upper panel) and reverses polarity at the mastoids (lower panel).

Adapted from Kujala and Näätänen (2001)

Recently, the MMN paradigm has been used to investigate syntactic processing in the auditory modality, within a theoretical approach supporting the automaticity of syntax (Hasting, Kotz, & Friederici, 2007; Pulvermüller & Shtyrov, 2003; Pulvermüller, Shtyrov, Hasting, & Carlyon, 2008; Shtyrov & Pulvermüller, 2002). In these studies, utterances of minimal sentences (subject Noun Phrase + verb), which were syntactically correct or violated subject–verb agreement, were contrasted as standard and deviant stimuli in an MMN paradigm. The utterances differed only in their final phoneme, which also determined their grammaticality (e.g., *we come* vs. **we comes*). The results, obtained comparing the identical acoustical stimulus in contexts differing for grammaticality, showed that amplitude modulations of the MMN depended on the syntactic congruency of the stimuli, thus demonstrating the automaticity of syntactic processing, that occurs in very early time windows (100-200 ms) and without focused attention.

P300 component. The P300 component, a positivity peaking around 300-500 ms after stimulus onset (see Figure 2.2), was first reported in 1965 (Sutton, Braren, Zubin, & John) and has been the most studied ERP component. Similarly to the MMN, it is also elicited in the context of oddball paradigms, but its occurrence is bound to the explicit detection of an unexpected stimulus (for example when participants are asked to react to the deviant stimuli by pressing a button, or silently counting the deviants). The amplitude of the P300 varies as function of task relevance, stimulus meaningfulness and probability of occurrence. An ongoing debate concerns whether the P300 reflects context updating in working memory (Ruchkin, Johnson, Canoune, Ritter, & Hammer,

1990) or inhibition mechanisms in the processing of expected targets (Schupp, Lutzenberger, Birbaumer, Miltner, & Braun, 1994).

Right Anterior Negativity (RAN) and Closure Positive Shift (CPS). RAN and CPS are electrophysiological components associated with the processing of prosodic information. RAN is a negativity observed in the right hemisphere between 300 and 500 ms after stimulus onset. It was first reported by Eckstein and Friederici (2005) in response to a mismatch between a syntactic structure and the expected prosody for that particular syntactic structure. CPS is a positive component with centro-parietal distribution, associated with the closure of the prosodic phrase, as defined by particular parameters such as pitch change, syllable lengthening, and pause (Steinhauer & Friederici, 2001).

N400 component. The N400 component is a negativity occurring between 200 and 700 ms (and peaking around 400 ms) after the presentation of a semantically incongruent stimulus (Kutas & Hillyard, 1980b). Although it is broadly distributed over the scalp, it is most pronounced over centro-parietal electrodes with a slight rightward shift (Kutas & Hillyard, 1980a). It has been associated with lexical-semantic processing, since its first report in 1980 for lexically anomalous words compared to the preceding sentence context (e.g. *He spread the warm bread with socks*). As Figure 2.4 shows, most words elicit the N400, whose amplitude (and latency) vary with experimental manipulation (Kutas & Van Petten, 1994). N400 amplitude correlates with the cloze-probability of the critical word, corresponding to the percentage of individuals that complete a particular sentence fragment with that word: the lower this index (cry in figure 2.4), the larger the N400 amplitude.

Further studies showed that the N400 does not vary as a function of the position of the critical word within the sentence (Kutas & Hillyard, 1983). Additionally, N400 effects have been replicated in a varieties of languages for stimuli presented in both visual and auditory modalities (see Kutas & Van Petten, 1994 for an extensive review); nevertheless, differences in latency, duration and localisation of the N400 for the two modalities have been found in some studies (Holcomb, Coffey, & Neville, 1992) but not replicated in others (Balconi & Pozzoli, 2005).

More recently, the N400 has been shown not only to occur in semantically anomalous sentences, but also in response to single words, for example showing higher amplitude for pseudowords than for real words (e.g. Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999). Moreover, it has been shown that the amplitude of the N400 also varies as a function of a word's frequency in general language use (Van Petten & Kutas, 1990).

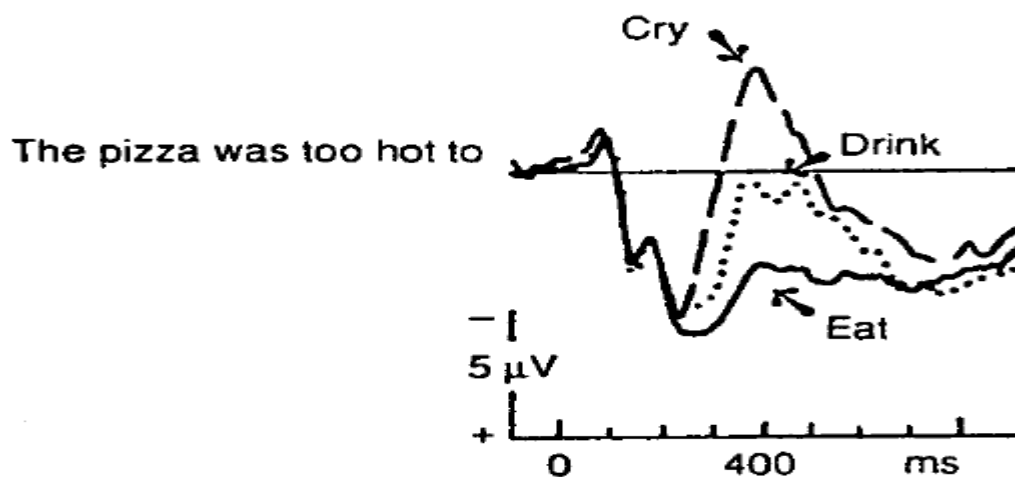


Figure 2.4: ERPs elicited by sentence-final words at midline central site, where the N400 amplitude is clearly related to word cloze-probability (adapted from Kutas & Van Petten, 1994)

The N400 has also been observed in priming paradigms⁹. In semantic priming paradigms the amplitude of the N400 increased in response to targets (words and pictures) that do not match the semantic expectation built up by previously presented primes (words, sentences and pictures); its amplitude was instead reduced when the targets were semantically related to the primes (Holcomb & Neville, 1990). Similarly, phonological priming, i.e. alliteration (shared word onset) or rhyme, has been found to reduce the amplitude of the N400 waveform (e.g. Praamstra, Meyer, & Levelt, 1994). Both semantic and phonological priming effects depend on the level of attention directed to the stimuli. In this context the N400 might belong to a broader category of “discordance negativities” (Perrin & Garcia-Larrea, 2003).

Recently conducted studies reveal the N400 to be sensitive to syntactic contexts too. For example, this negativity has been found to be evoked when thematic role assignment is impossible (Bornkessel, Schlesewsky, & Friederici, 2002), and when grammatical rules are violated with consequences that are interpretative rather than purely formal in nature, as incorrect choice of subject case in Hindi (Choudhary, Schlesewsky, Roehm, & Bornkessel-Schlesewsky, 2009).

Given this brief overview of recent findings, the functional meaning of the N400 component has been reviewed. The general idea that the N400 component reflects the process of semantic integration of the critical word with the working context, or more generally an index of lexical and semantic processing, is nowadays the object of open debate.

⁹ Priming paradigms are based on the assumption that, while reacting to an object, we benefit from previous exposure to the same or a related object. In semantic priming paradigms the benefits are induced by the presentation of semantically related words, while in phonological priming paradigms the benefits are induced by the presentation of words/pseudowords with phonologically similar features (i.e., rhyme or initial phoneme).

Left Anterior Negativities: LAN and ELAN. Several studies have reported left anterior negativities within a time-window ranging from 100 to 500 ms in response to different type of syntactic violations (Friederici, 1995). The typical distribution of these components, as the name suggests, is frontally localised and more pronounced over left than right electrodes (Coulson, King, & Kutas, 1998; Friederici, 1995; Osterhout & Mobley, 1995). They have been shown in syntactic violation paradigms (when syntactically correct and incorrect sentences are auditorily or visually presented), usually followed by a late positivity, named P600.

An Early Left Anterior Negativity (ELAN) has been found in response to phrase structure violation in English (e.g., *Max's of proof the theorem*; Neville, Nicol, Barss, Forster, & Garrett, 1991) and German (e.g., *Der Freund wurde im __ besucht [the friend was in-the __ visited]*; Friederici, Pfeifer, & Hahne, 1993). Due to its early onset, generally occurring approximately 100-200 ms after stimulus onset, the ELAN has been interpreted to reflect highly automatic processing of initial structure building (Friederici, 1995). According to recent neurocognitive models (Friederici, 2002), the ELAN is the electrophysiological correlate of the first phase of auditory sentence comprehension, during which the syntactic structure is formed on the basis of information about word category.

A second Left Anterior Negativity (LAN), with an onset between 300 and 500 ms, has been found in response to morphosyntactic violations, such as gender, number and tense agreement (Coulson et al., 1998; Friederici et al., 1993). This negativity has been either interpreted as a “pure morphosyntactic” component, reflecting the detection of the morphosyntactic congruency errors (Friederici, 1995), or as the result of non-specific working memory processes (Coulson et al., 1998). Given its onset (300-500 ms), resembling that of the N400 component, Friederici’s neurocognitive model of auditory sentence comprehension (2002) proposed lexical-semantic and morphosyntactic processes to take place simultaneously in this time-window, during thematic role assignment.

With respect to other electrophysiological components associated with language processing, left anterior negativities seem to be cross-linguistically less robust, as other studies conducted in various languages differing from English and German (such as Italian and Dutch) failed to find left anterior negativities with subject-verb agreement violations (e.g. Balconi & Pozzoli, 2005; Hagoort, Brown, & Groothusen, 1993).

P600 component. As already mentioned, in addition to left anterior negativities, syntactic anomalies have been shown to elicit a positive deflection with a centro-parietal distribution and a maximal peak around 600 ms after stimulus onset, thus named P600 (Osterhout & Holcomb, 1992) or Syntactic Positive Shift (Hagoort et al., 1993). This positivity has been connected to several types of (morpho)syntactic violations, namely subject-verb agreement (e.g. Balconi & Pozzoli, 2005;

Coulson et al., 1998; De Vincenzi et al., 2003; Hagoort et al., 1993; Osterhout & Mobley, 1995; Rossi, Gugler, Hahne, & Friederici, 2005; Vos, Gunter, Kolk, & Mulder, 2001), gender agreement (e.g. Barber & Carreiras, 2005), person agreement (Silva-Pereyra & Carreiras, 2007) and phrase structure (Hahne & Friederici, 1999; Neville et al., 1991), including verb tense violations (Osterhout & Nicol, 1999). Due to its association with syntactic violations, the P600 has been initially and mainly interpreted as reflecting controlled processes of syntactic repair. However, the P600 has also been reported for syntactic ambiguities and less preferred syntactic structures or garden-path-sentences (e.g., Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Osterhout & Holcomb, 1992). Under these conditions, the P600 is thought to reflect a process of reanalysis of the previously misinterpreted information (Friederici, 1995, 2002). Within Friederici's model (1995, 2002), the P600 corresponds to the third phase of auditory sentence processing, during which lexical-semantic and morphosyntactic processes are integrated. Finally, the P600 has been shown to be associated with sentences of increased syntactic complexity as well, thus reflecting syntactic integration difficulty (Kaan, Harris, Gibson, & Holcomb, 2000).

In support to the controlled nature of the P600 component, compared to the automaticity of left anterior negativities, there is evidence that both stimulus frequency (Hahne & Friederici, 1999) and task requirements (Gunter & Friederici, 1999) modulate the amplitude of the P600 component. By contrast, the modality of presentation of stimuli does not influence the onset latency and amplitude of this component (Balconi & Pozzoli, 2005; Hagoort & Brown, 2000), showing that the P600 reflects high-level processes of sentence comprehension.

Recent findings extend the functional interpretation of this component beyond purely grammatical anomalies. The P600 has been shown in response to thematic violations (e.g., *the meal was devoured/devouring...*; Kim & Osterhout, 2005), and semantic violations in relative clauses (e.g., *Duch sentences like: the cat that fled from the mice ran through the room*; Kolk, Chwilla, van Herten, & Oor, 2003). Most importantly, several P600 effects have been reported in experiments outside the linguistic domain. For example, P600-like effects were found in response to incongruous musical sequences (Patel, Gibson, Ratner, Besson, & Holcomb, 1998), spelling mistakes (Münte, Heinze, Matzke, Wieringa, & Johannes, 1998) and violations of action sequences (Gunter, Knoblich, Bach, Prinz, & Friederici, 2002). The latter evidence has opened a debate on the specific linguistic nature of the P600, addressing the question whether the P600 is a distinct component or solely a delayed P300 component (see previous section). Osterhout, McKinnon, Bersick, and Corey (1996) directly compared the two components and concluded that they should be considered distinct, given the fact that they differ with respect to sensitivity to stimulus and task manipulation.

2.3 Subject-verb agreement paradigm

As already mentioned in previous sections, the subject-verb agreement paradigm provides reliable ERP effects. As it has been widely used with healthy populations in different languages (see Table 2.1 for a review of major investigations) it offers a strong starting point for the study of special populations, such as L2 learners (e.g. Osterhout et al., 2008) or language-impaired group (e.g., Hagoort, Wassenaar, & Brown, 2003; Rispens, Been, & Zwarts, 2006).

The typical electrophysiological pattern associated with subject-verb agreement violations consists of a LAN (mainly shown at F3 and F7 electrodes) followed by the P600 component (with maximal amplitude at posterior electrodes). This bi-phasic pattern has been found in several electrophysiological investigations (e.g. De Vincenzi et al., 2003; Osterhout & Mobley, 1995; Vos et al., 2001) but has not been replicated in others (e.g. Atchley et al., 2006; Balconi & Pozzoli, 2005; Hagoort et al., 1993; Münte, Matzke, & Johannes, 1997; Osterhout et al., 1996, see Table 2.1). In particular, studies differ in the presence/absence or localisation of the LAN component. Differences in agreement morphology features across languages might be the cause of inconsistencies found in the ERP pattern. In addition, it should be noted that the modality of presentation (visual or auditory) of the linguistic material can also modulate the amplitude of the components (anterior negativities are more easily detected with auditory presentation; Hagoort & Brown, 2000), as well as the presence/absence of an additional task, mainly grammaticality judgement task (anterior negativities are more easily detected with explicit task requirements; Osterhout & Mobley, 1995).

Although the most studied subject-verb agreement violations involve number, a growing number of ERP studies have further investigated person agreement (e.g., Rossi, 2005; Silva-Pereyra & Carreiras, 2007). In addition, recent studies have investigated agreement between determiner and noun, as well as between noun and adjective concerning both number and gender (concerning both number and gender, e.g. Barber & Carreiras, 2005), aiming to extensively investigate agreement processes. Despite the theoretical relevance of these studies, these will not be further described in the present dissertation.

Authors (language)	Example of stimuli	Task	Results
Hagoort et al., 1993 (Dutch)	<i>The spoilt child</i> (3 rd sing.) <u>throw</u> (3 rd plur.) <i>the toys on the floor</i>	Reading without additional task	Centro-parietal P600 (500-700)
Osterhout & Mobley, 1995 (English)	<i>The elected officials</i> (3 rd plur.) <u>hopes</u> (3 rd sing.) <i>to succeed</i>	Reading without additional task	Early negativity (50-150) maximal in Pz + P600 (500-800)
		Reading with grammaticality judgement task	Early negativity (150-300) posterior and right lateralised + LAN (300-500) + Right P600 (500-800)
Osterhout et al., 1996 (English)	<i>The doctor</i> (3 rd sing.) <u>believe</u> (3 rd plur.) <i>the patient will recover</i>	Reading without additional task	Posterior P600 (500-800) + non significant frontal negativity (300-500)
		Reading with grammaticality judgement task	P600 (500-800)
Munte et al., 1997 (German)	<i>Der mann</i> (3 rd sing.) <u>trinken</u> (3 rd plur.) <i>das Bier</i>	Reading with grammaticality judgement task	Centro-parietal P600 (500-900)
Coulson et al., 1998 (English)	<i>Every Monday he</i> (3 rd sing.) <u>mow</u> (3 rd plur.) <i>the lawn</i>	Reading with random comprehension questions	Right centro-parietal negatività (300-500) + Centro-parietal P600 (500-800)
Hagoort & Brown, 2000 (Dutch)	<i>The spoilt child</i> (3 rd sing.) <u>throw</u> (3 rd plur.) <i>the toys on the floor</i>	Reading, without additional task	Bi-phasic P600: anterior (500-750) posterior (750-1000)
		Listening, without additional task	Bilateral anterior negativity (300-550) + P600 (500-1250)
Vos et al., 2001 (Dutch)	<i>The tourists</i> (3 rd plur) <u>have a busy schedule and visits</u> (3 rd sing) <i>the theater that very famous is</i>	Reading, without additional task	Negativity (250-450) + P600
De vincenzi et al., 2003 (Italian)	<i>The old waiter</i> (3 rd sing.) <u>wait on</u> (3 rd plur.) <i>vacantly</i>	Reading with comprehension questions	LAN (350-450) + P600 (500-700)
Balconi & Pozzoli, 2005 (Italian)	<i>The door</i> (3 rd sing.) <u>are</u> (3 rd plur.) <i>open</i>	Reading with and without grammaticality judgement task; Listening with and without grammaticality judgement task	P600 (550-700)
Rossi, et al., 2005 (German)	<i>The child</i> (3 rd sing.) <u>at kindergarten sing</u> (2 nd sing.)	Listening with grammaticality judgement task	Frontal and central LAN (450-650) + P600 (800-1300)
Atchley et al., 2006 (English)	<i>Where <u>do</u></i> (3 rd plur.) <i>a boy</i> (3 rd sing.) <i>like to play?</i>	Listening with grammaticality judgement task	P600 (623-673)
Sylva-Pereyra & Carreiras, 2007 (Spanish)	<i>We</i> (1 st plur.) <u>jump</u> (1 st sing.) <i>in the backyard</i>	Reading with grammaticality judgement task	Right and central anterior negativity + P600 (500-900)

Table 2.1. Summary of the main ERP studies investigating subject-verb number agreement violation

2.4 Electrophysiology in the study of language development

Recently, several reports of the ERP correlates of language processing in developmental populations have confirmed the behavioural data on language acquisition (see Guasti, 2002 for an extensive review), providing further knowledge on the underlying cognitive and neural mechanisms. Friederici and colleagues have extensively addressed the question of whether there is a continuous development from early to later stage of language use, or whether young children process language in a fundamentally different way compared to adults (see Friederici 2005 for a review of their studies). Figure 2.5 (adapted from Friederici, 2005) summarises the main findings concerning the developmental stages of auditory language comprehension, as revealed by their electrophysiological correlates. The similarities between the brain response patterns observed in children and adults support the view that language develops in a continuous manner.

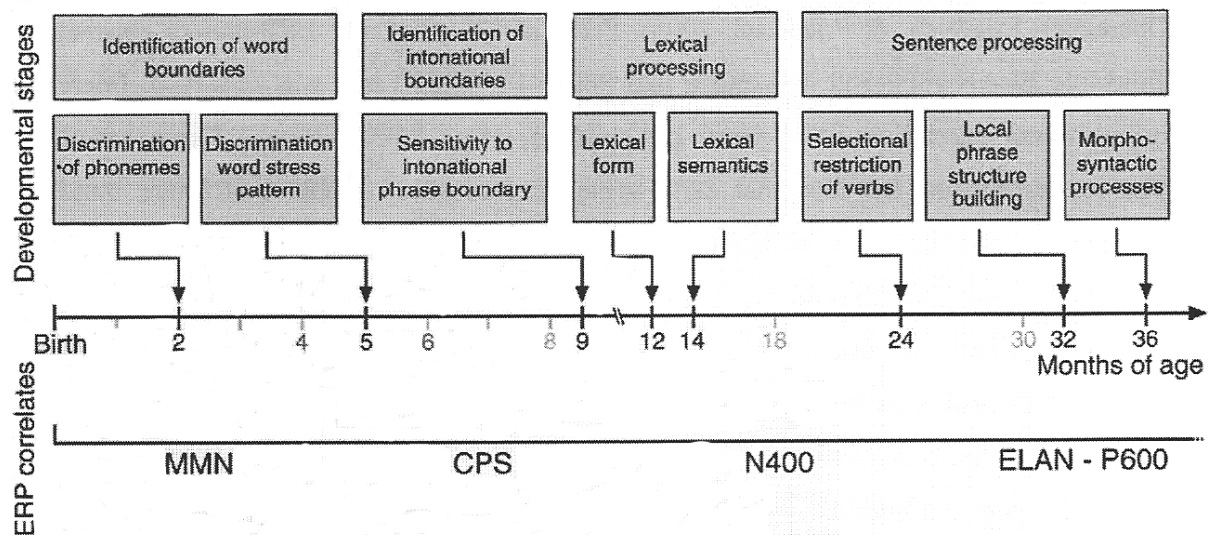


Figure 2.5. Schematic overview of the developmental stages of auditory language perception/comprehension (adapted from Friederici, 2005)

The infant's initial steps into language are bound to phonological processing. Using the MMN paradigm, some studies have investigated newborns' and young infants' ability to discriminate between different phonemes, demonstrating that this ability is present quite early, with 2-month-old awake infants showing an adult-like MMN (Friedrich, Weber, & Friederici, 2004) in response to vowel duration discrimination in a consonant-vowel syllable. A few ERP studies have investigated the discrimination of stress pattern, using the same MMN paradigm, and showed that 5-month-olds are able to discriminate two-syllable pseudo-words stressed on the first syllable from those stressed on the second syllable (C. Weber, Hahne, Friedrich, & Friederici, 2004). Finally, sensitivity to intonational phrase boundary has also been demonstrated to develop in the first year of life, as

revealed by studies showing an adult-like CPS at the offset of each intonational phrase boundary in 9 month-olds (Pannekamp, Weber, & Friederici, 2006).

With respect to lexical-semantic processing, an N400 component thought to reflect semantic integration has been found at the word level in 14-month (Friedrich & Friederici, 2005a) and 19-month-old infants, but not in 12-month-olds (Friedrich & Friederici, 2005b) while looking at pictures and listening to words matching or not matching with the object's name. With respect to semantic processing at the sentence level, an N400-like effect was reported in German-speaking children aged 19 and 24 months in response to semantically incongruous words compared to semantically highly expected words (*Die Katze trinkt die Milch/*den Ball; the cat drinks the milk/*ball*; Friedrich & Friederici, 2005c).

Adult-like electrophysiological correlates of syntactic processing have been found in 32-month-olds who passively listened to correct sentences (*Der Löwe brüllt; the lion roars*) and sentences with a local phrase structure violation (*Der Löwe im __ brüllt; the lion in-the __ roars*; Oberecker, Friedrich, & Friederici, 2005). Specifically, a bi-phasic ERP-pattern consisting in a child-like ELAN (300-500 ms) and a late P600 (1100-1500 ms) was observed. Interestingly, by using the same paradigm in 24-month-olds, only a P600 (1100-1700 ms) was observed. The results support the idea that syntactic processes of phrase structure building are in place relative early during language development, but they are less automatic than those shown by adults. To address the question of age-related changes, Hahne, Eckstein, and Friederici (2004) presented sentences involving the same phrase structure violation embedded in more complex syntactic structures (**Das Eis wurde im __ gegessen [The ice cream was in-the __ eaten*) to children between 6 and 13 years. An adult-like ELAN (100-300 ms) was only observed in the 13-year-old children, whereas younger children showed a delayed bilaterally-distributed anterior negativity (400-600 ms). The bilateral distribution was hypothesised to reflect the involvement of prosodic processing (generally expressed in an early negativity in the right hemisphere, ERAN), which is thought to support syntactic processing, especially during language development. With respect to the P600 component, this was present in children of all age groups, although it had a delayed onset in 6-year-old children (1250-1500), that was observed to decrease with age.

Finally, a few studies have addressed the electrophysiological correlates of morphosyntactic processing in early development. Silva-Pereyra and colleagues (2005) used a morphosyntactic paradigm consisting in the auditory presentation of English sentences with morphosyntactic violations (**My uncle will watching the movie*). They reported a P600-like positivity in 3- and 4-year-old children (Silva-Pereyra, Rivera-Gaxiola, & Kuhl, 2005), but not in 30-month-old children (Silva-Pereyra, Klarman, Lin, & Kuhl, 2005), whereas no LAN effect was observed at either age. Atchley and colleagues (2006) presented two syntactically anomalous conditions to children (aged

8-13) and adults. In particular, English wh-questions were used (*where does a boy like to play?*), with violations consisting either in the verb drop violation (**where a boy like to play?*) or in subject-verb agreement violation (**where do a boy like to play?*). The analysis only investigated the P600 time-window effect. No differences concerning scalp distribution, amplitude and latency have been found between children and adults in the P600 elicited by verb drop violations. However, for the agreement violation condition, children showed a longer component duration, reflecting an additional effort, and thus confirming the later complete acquisition of morphosyntactic processes, within the syntactic domain.

2.5 Electrophysiology in the study of DD and SLI

2.5.1 Phonemic discrimination and speech processing in DD

A number of studies have investigated the electrophysiological correlates of phonemic discrimination in children and adults with DD, as well as in children at risk for DD, through the MMN paradigm (see Section 2.2). As it emerges from recent reviews (Bishop, 2007; H. Lyytinen et al., 2005; Schulte-Körne & Bruder, 2010), these studies (summarised in Table 2.2) are highly variable in methodological details, such as number and characteristic of the participants, syllables used to elicit the MMN, presentation rate, and Time Window (TW) in which the MMN is identified (Bishop, 2007).

Despite these differences, speech-specific processing deficits to Consonant-Vowel (CV) stimuli have been shown quite consistently in both children and adults (Schulte-Körne & Bruder, 2010). Kraus and colleagues (1996) first reported attenuated MMN in a broadly defined group of children and adolescents with learning disabilities. Participants were firstly tested on their ability to discriminate between two CV syllables (/da/ vs. /ga/: spectral change; and /ba/ vs. /wa/: temporal change). Therefore, MMN amplitude and duration were measured in 21 children with poor discrimination and compared to an equal number of children with good discrimination. In comparison to control children, poor perceivers showed a discrimination deficit, reflected in a diminished amplitude of the MMN, that was specific for contrasts differing in spectral content (/da/ vs. /ga/), but not for contrasts differing in their temporal content (/ba/ vs. /wa/). Behavioural discrimination and MMN measures in these children were highly correlated.

A number of subsequent studies replicated these first results, showing diminished MMN response to deviant CV syllables in both children (Banai, Nicol, Zecker, & Kraus, 2005; Bradlow et al., 1999; Csépe, 2003; Hommet et al., 2009; Schulte-Körne, Deimel, Bartling, & Remschmidt, 1998; Sharma et al., 2006) and adults (Hommet et al., 2009) with DD. MMN deficits have also been

found in Chinese dyslexic children (Meng et al., 2005), although in a very early, atypical TW (0-100).

Authors (Language)	Participants	Stimuli	Results
Kraus et al., 1996 (English)	21 good perceivers and 21 poor perceivers (from a sample of normal and learning impaired children, aged 6-15)	/da/ vs. /ga/	Children with learning disabilities show smaller MMN than controls
Schulte-Körne et al., 1998 (German)	19 DD children (M=12.5) and 15 controls	/da/ vs. /ba/	group difference in the TW 303-620
Bradlow et al., 1999 (English)	32 children with Learning Problems (LP) and 72 controls (age range 6-16)	/da/ vs. /ga/	Diminished responses in the LP group, but no differences in a “lengthened transition duration” condition
Heim et al., 2000 (German)	10 DD children (aged 8-13) and 9 controls	/da/ vs. /ga/	No differences in the amplitude MMN. MEG: difference in the localisation
Schulte-Körne et al., 2001 (German)	12 DD adults (M=30) and 13 controls	/da/ vs. /ga/	Group differences in the last time windows: 460-550 and 550-640 ms
Breier et al., 2003 (English)	12 DD children and 11 controls	/ga/ vs. /ka/	Correlation between increased activation in right temporo-parietal areas and reduced performance on phonological processing measures in DD children.
Banai et al., 2005 (English)	74 children with Learning Disability: normal (46) vs. abnormal brainstem timing (28) and 46 control children (aged 8-12)	/ga/ vs. /da/	MMN duration and area: LD abnormal brainstem < LD abnormal brainstem < controls
Lachmann et al. 2005 (German)	16 DD children: dyseidetics (8) vs. dysphonetics (8) and 12 control children (aged 8-11)	/da/ vs. /ba/	Absent MMN in dyseidetic dyslexics
Sharma et al., 2006 (English)	23 reading disorder children (RD); 15 compensated reader (CR) and 21 controls (CG), aged 8-12	/da/ vs. /ga/	Difference CG vs. RD: smaller deviant /ga/- evoked area in the RD group. Correlation between the area of the /ga/ deviant and NW repetition
Alonso-Bua et al., 2006 (Spanish)	31 children with “reading difficulties” and 24 controls (aged 4-8)	/ba/ vs. /da/	No differences in MMN amplitude, but only in latency. Reduced LDN amplitude and delayed latencies.
Paul et al., 2006 (German)	58 DD children and 21 controls (aged 9)	/ba/ vs. /da/	The groups did not differ in MMN amplitude or latency
Sebastian & Yasin, 2008 (English)	10 DD adults and 10 controls (aged 18-22)	/ba/ vs. /da/ /ta/ vs. /ka/	No differences for speech stimuli
Hommet et al., 2009 (French)	12 DD children and 14 controls (aged 8-12); 15 dyslexic adults and 16 controls (aged 14-23)	/da/ vs. /ga/	Differences in amplitude of MMN (both children and adults) and LDN (only children). Difference also in latency and topography.

Table 2.2 Summary of main ERP studies on phonemic discrimination in dyslexic populations

Only a few studies failed to find differences between dyslexic individuals and controls in the amplitude of the MMN, but reported other differences between groups (Alonso-Bua, Diaz, & Ferraces, 2006; Heim et al., 2000; Schulte-Körne, Deimel, Bartling, & Remschmidt, 2001). Schulte-Körne and colleagues (2001) presented a /da/ vs. /ga/ contrast to adults with DD, and reported only a diminished amplitude in a delayed component, called Late Discrimination Negativity (LDN); this

component reflects faulty long-term memory traces (Näätänen, 2001) instead of deficits in phoneme discrimination. Differences concerning amplitude and latency of this late component between children with and without DD have been recently found by Alonso-Bua et al. (2006), in addition to differences in MMN latency. Using Magnetoencephalography (MEG)¹⁰, Heim et al. (2000) found only differences in scalp distribution, when comparing 10 children with DD with 9 controls in the /da/ vs. /ga/ contrast. Finally, only a couple of ERP/MEG studies reported no speech-processing deficits in DD (Paul, Bott, Heim, Wienbruch, & Elbert, 2006; Sebastian & Yasin, 2008). Furthermore, an other study reported anomalies in MMN in only one subgroup of DD children (Lachmann, Berti, Kujala, & Schroger, 2005).

A number of studies have additionally investigated the ERP correlates of phonemic discrimination in children at risk for DD at different ages (Bitz, Gust, Spitzer, & Kiefer, 2007; Maurer, Bucher, Brem, & Brandeis, 2003; Molfese, 2000). These studies found that, even at a very early age, ERP responses can differentiate children with and without risk for DD, and are predictive of later reading skills. In reviewing the finding of the Jyväskylä Longitudinal Study of Dyslexia, Lyytinen (2005) concluded that the most consistent result of their studies was in the topography of ERP responses: high-risk children showed right hemisphere dominant responses to speech sounds, whereas the control group showed left hemisphere responses.

As already discussed when reviewing phonological deficits in DD (section 1.2.1), the issue of whether phonemic discrimination is speech-specific (due to a phonological processing deficit) or is based on a more general auditory impairment is still controversial (e.g., Mody et al., 1997). However, a growing number of ERP studies showing deficits concerning the discrimination and reproduction of non-speech stimuli have pointed towards a more general and basic problem in auditory processing (Baldeweg, Richardson, Watkins, Foale, & Gruzelier, 1999; Kujala et al., 2006). It is clear that certain non-speech deficits are apparent in DD, particularly concerning the discrimination of rapid frequency changes and the detection of differences in complex tone patterns, both of which are relevant to speech processing and phonemic discrimination (for a recent review see Schulte-Körne & Bruder, 2010).

2.5.2 Phonological processing in DD

Electrophysiological correlates of phonological processing in DD has been investigated mainly through phonological priming paradigms (Ackerman, Dykman, & Oglesby, 1994; Bonte &

¹⁰ Magnetoencephalography (MEG) consists in the recording of magnetic fields produced by electrical currents occurring in the brain. Although EEG and MEG signals originate from the same neurophysiological processes, there are important differences. The main difference concerns their spatial resolution: magnetic fields are less distorted than electric fields, which results in a better spatial resolution of the MEG.

Blomert, 2004; Jednorog, Marchewka, Tacikowski, & Grabowska, 2010; McPherson & Ackerman, 1999; McPherson, Ackerman, Holcomb, & Dykman, 1998; McPherson, Ackerman, Oglesby, & Dykman, 1996; Russeler, Becker, Johannes, & Münte, 2007) which require phonemic awareness skills, such as rhyme judgement (Ackerman et al., 1994; McPherson et al., 1998; McPherson et al., 1996; Russeler et al., 2007) or alliteration (words and/or pseudowords starting with the same phonemes Bonte & Blomert, 2004; Jednorog et al., 2010; McPherson & Ackerman, 1999). The results, in both considering visual and auditory presentation, generally show impairment at the phonological level.

A series of studies conducted by McPherson, Ackman and colleagues have focused on phonological priming, using different modalities of stimulus presentation: written words and pseudowords (Ackerman et al., 1994), pictures (McPherson et al., 1996), or auditory presentation of real words (McPherson & Ackerman, 1999; McPherson et al., 1998). Their findings generally pointed towards a non-automatic processing of phonological features in DD. In particular, they described different subgroups of reading disabled participants: Dysphonetic dyslexic children, characterised by difficulties translating orthography into phonology, and Phonetic dyslexic children, characterised by slower functioning and reduced capacity in preparing for a response.

The following studies preferably used auditory presentation. A word priming task has been employed by Bonte and Blomert (2004) to implicitly assess early phonological processing, using an auditory lexical decision task, in combination with alliteration priming, in Dutch-speaking children with DD. The results showed anomalous speech processing, as indexed by deviant priming effects in the earlier time windows encompassing the N1 and N2 components, whereas later N400 priming effects were comparable to those of normal readers. The authors concluded that only early phonetic/phonological processing is abnormal in children with DD, whereas later semantic processing proceeds normally.

In a very recent study by (Jednorog et al., 2010), phonological priming has been tested in Polish children with DD by employing a slightly different paradigm in which, instead of one prime word, six prime words preceded the target word. In the phonological/alliterative task, children listened to six words, identical in two or three initial phonemes, while the congruency of the seventh word was manipulated. The results for DD children showed a clear reduced N400 amplitude in the incongruent condition, and enhanced N400 in the congruent condition. The authors interpreted this finding as a confirmation of the existence of a phonological deficit in DD, involving both phonological integration and detection of phonological incongruency.

2.5.3 Lexical and semantic processing in DD

ERP correlates of lexical mechanisms and semantic processing have been extensively investigated in children and adults with DD. Most of these studies employed semantic priming and word recognition tasks, with both written (Csépe, Szucs, & Honbolygo, 2003; Johannes, Mangun, Kussmaul, & Münte, 1995; Russeler et al., 2007; Russeler, Probst, Johannes, & Münte, 2003; Silva-Pereyra et al., 2003; Stelmack & Miles, 1990; Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988; Taroyan & Nicolson, 2009) and auditory presentation (Helenius, Parviainen, Paetau, & Salmelin, 2009; Jednorog et al., 2010; Torkildsen, Syversen, Simonsen, Moen, & Lindgren, 2007) of repeated words.

As shown in Appendix 2A, these studies had yielded mixed and inconclusive results. Some authors reported delayed, reduced or absent N400 word priming effects for individuals with DD (Johannes et al., 1995; Stelmack & Miles, 1990; Stelmack et al., 1988). These results were generally interpreted as reflecting problems in the engagement of long-term semantic memory.

Neural signatures of auditory word recognition and word repetition have been further investigated through MEG, comparing young adults with DD, young adults with a history of SLI and control participants (Helenius et al., 2009). In this study, the size of the repetition effect decreased from control participants through dyslexics to SLIs, showing impaired short-term maintenance of linguistic activation, when advancing from milder to more severe language impairment. Interestingly, Norwegian children at risk for DD (aged 20 and 24 months) showed similar delayed or absent N400 incongruity effect in auditory lexical-semantic priming tasks (Torkildsen et al., 2007), showing that deficiencies in young children at-risk for dyslexia are not restricted to perceptual and lower-level phonological abilities, but also affect higher order linguistic skills such as lexical and semantic processing.

Other studies on semantic priming have been recently conducted on children and adults with DD (Jednorog et al., 2010; Russeler et al., 2007) using semantically-related words presented in either auditory or written forms. Both studies found semantic priming N400 effects comparable to controls, although with delayed onset (Jednorog et al., 2010) or with longer persistence (Russeler et al., 2007). Interestingly, as already reported, the same participants presented greater anomalies in the N400 component elicited by the phonological priming.

In contrast, normal N400 priming effects in dyslexic individuals have been observed in other studies (Russeler et al., 2003; Silva-Pereyra et al., 2003). In particular, Silva-Pereyra and colleagues (2003) presented Spanish-speaking children with impaired reading abilities with a visually presented figure-and-word categorisation task (animal vs. non-animal stimuli). In the behavioural task DD children showed longer reaction times and worse performance compared to controls. ERPs

additionally revealed longer and larger P2 amplitudes, smaller amplitudes and longer P300 latencies, but no differences in the N400 component with respect to controls. According to the authors, the semantic processing underachievement in poor reader children is not a semantic deficit per se, but the late reflection of an early word codification problem, deficient use of attentional resources and lack of target identification during reading.

Semantic processing in DD has been additionally investigated within sentence context, during reading (Brandeis, Vitacco, & Steinhausen, 1994; Helenius, Salmelin, Service, & Connolly, 1999; Neville, Coffey, Holcomb, & Tallal, 1993; Robichon, Besson, & Habib, 2002; Schulz et al., 2008) or spoken auditory presentation (Helenius et al., 2002; Mody, Wehner, & Ahlfors, 2008; Sabisch, Hahne, Glass, von Suchodoletz, & Friederici, 2006). In most of these studies, the typical violation paradigm was employed, by comparing the electrophysiological responses to sentences with congruent and incongruent endings (generally eliciting an enhanced N400 component). Studies on semantic integration during reading consistently reported anomalies in the N400 component, reflected in delayed latency and/or reduced amplitude of the component in some studies (Brandeis et al., 1994; Helenius et al., 1999; Schulz et al., 2008) and in increased amplitude of the component in other studies (Neville et al., 1993; Robichon et al., 2002). Instead of interpreting the results as a clear semantic processing deficit, some of the studies concluded that dyslexic individuals use qualitatively different modalities to process word meaning, as reflected by qualitatively different patterns of neural activation (Brandeis et al., 1994). According to Neville et al. (1993), dyslexic children rely more on context for comprehension. Furthermore, according to Helenius et al. (1999) dyslexic individuals rely on sublexical word recognition and occasionally mistook a correctly beginning word for the one they had expected, whereas control individuals perceived words as wholes. In these studies, however, the written presentation of the sentences did not allow the authors to conclude that semantic processing per se is impaired, but only that semantic processing during reading is weaker.

The few studies that auditorily presented semantically incongruous sentences to individuals with DD (Helenius et al., 2002; Mody, Wehner, & Ahlfors, 2008; Sabisch, Hahne, Glass, von Suchodoletz, & Friederici, 2006) failed to find a clear semantic processing impairment. Sabisch and colleagues (2006) found no differences in the N400 component between German-speaking dyslexic children and age-matched controls presented with semantic violation (where selectional restriction of the verb were violated: *Der Vulkan wurde gegessen* [*The volcano was eaten*]).

Other studies traced N400 anomalies in response to semantic violations back to phonetic-phonological deficits in adults and children with DD (Helenius et al., 2002; Mody et al., 2008). Through a MEG study, Mody et al. (2008) compared good and poor readers (7-13 years old) on the auditory perception of words varying in phonological contrast, in congruent versus incongruent

sentence contexts¹¹. The results showed that poor readers processed semantically incongruent sentences as congruent in the phonologically similar condition (e.g. *The boy rolled the doll*: congruent word *ball*), but not in the phonological dissimilar condition (e.g. *The boy rolled the hall*: congruent word *ball*) due to an anomalous phonological processing, consistent with a phonological account of reading disability. Helenius et al. (2002) also employed MEG to compare dyslexic and control adults during auditorily presented sentences with sentence-ending words either semantically appropriate or inappropriate to the preceding sentence context, where half of the inappropriate final words shared two or three initial phonemes with the highly expected semantically appropriate words. The results in DD individuals showed an abnormally strong pre-semantic N100 followed by a delayed N400, and were interpreted as delayed semantic activation resulting from difficulties at the presemantic-phonological stage.

2.5.4 Morphosyntactic and syntactic processing in DD

ERP correlates of (morpho)syntactic processing have been less extensively investigated in DD. Only a recent study (Russeler et al., 2007) employed written word-pairs in an attempt to compare with a priming paradigm phonological, semantic and syntactic processing. Dyslexic and control adults were asked to judge the grammaticality of written word pairs consisting of a definite article and a noun agreeing or disagreeing with respect to gender (e.g. *der Hut* [*the hat*, correct: both article and noun have masculine gender]; *das Chemie* [*the chemistry*, incorrect: the article has neutral gender while the noun has feminine gender]). The results showed that groups differed in the onset and the persistence of the elicited negativity (with dyslexics presenting delayed onset and a longer persistence), as well as in the response times (with dyslexic adults presenting prolonged response times) generally indicating syntactic processing difficulties.

Other ERP studies have investigated (morpho)syntactic processing in sentence context (Breznitz & Leikin, 2000, 2001; Leikin, 2002; Rispens, Been, & Zwarts, 2006; Sabisch et al., 2006). A series of studies have reported anomalous cortical responses in Hebrew-speaking dyslexic adults processing sentence components with different grammatical functions during a reading task (Breznitz & Leikin, 2000, 2001; Leikin, 2002). In particular, the effects of syntactic function and word position were addressed during reading word-by-word Subject-Verb-Object sentences at varying presentation rates. The results showed that the processing of words in accordance with their

¹¹ Similar phonological contrasts had been previously assessed in the same participants through an auditory oddball paradigm in which the 'deviant' stimuli (/bat/, /kat/, /rat/) differed in the degree of phonological contrast (1 vs. 3 features) from a repeated standard word (/pat/). Source analysis of the MEG data showed that compared to good readers, poor readers had reduced left-hemisphere activation to the most demanding phonological condition (/pat/ vs /bat/) reflecting their difficulties with phonological processing (Wehner, Ahlfors, & Mody, 2007).

grammatical functions is slower among dyslexic readers and requires more substantial effort. They processed grammatical functions using the primitive and effortful word-order strategy, while normal readers mostly used a predicate-oriented strategy.

More interestingly, ERP anomalies have also been found in response to the auditory presentation of (morpho)syntactic violations (Rispen et al., 2006; Sabisch et al., 2006). Sabisch et al. (2006) presented German-speaking DD children and controls with phrase structure violations in passive sentences. Sentences consisted of a noun, an auxiliary, and a preposition, but instead of a noun or an adjective expected to follow the preposition, a past participle was presented immediately after it (e.g. *Das Eis wurde im __ gegessen* [*The ice cream was in-the __ eaten*], same sentences used in Hahne and colleagues, 2004). The same P600 component was shown in control and dyslexic children, whereas differences were found in the early components. Control children showed an early starting bilaterally distributed anterior negativity (Hahne et al., 2004). In contrast, dyslexic children presented a delayed left lateralised anterior negativity. This result is discussed in terms of the delay, in dyslexic children, of the early and presumably highly automatic processes of phrase structure building. Furthermore, the bilateral distribution of the early effect in control children was taken to suggest an involvement of prosodic processes localised in the right hemisphere (RAN component, described in Section 2.2) in addition to the left hemispheric syntactic processes. The left-lateralised negativity in dyslexic children was interpreted in the sense of phonological impairment in dyslexic children (i.e. no right hemisphere contribution) which might lead to an impairment of syntactic processes.

Rispen et al. (2006) have investigated the presence and latency of the P600 component in response to subject-verb agreement violations in Dutch-speaking adults with DD (same stimuli of the behavioural experiment described in Section 1.2.2.2.2). Despite the absence of differences between dyslexics and controls in judging the grammaticality of the sentences, the ERP data revealed subtle differences between groups, particularly related to latency (the P600 tended to peak later in the dyslexic group compared to the control group) and lateralisation (for dyslexic participants the P600 was less strong in the left hemisphere compared to the midline and right posterior region, while there were no differences between the presence of the P600 in the three areas in the controls). Moreover, dyslexic participants, as a group, did not show the component in response to sentences with a plural subject (e.g., *de rare clowns* [3rd plural] *maakt* [3rd singular] *een grapje*; *the funny clowns* [3rd plural] *makes* [3rd singular] *a joke*). This finding was interpreted in relation to the higher complexity of plural with respect to singular forms, and led to the conclusion that ‘*brain activation involved in syntactic repair is more affected by linguistic complexity in developmental dyslexia compared with non-dyslexic individuals*’ (p. 134).

2.5.5 Morphosyntactic and syntactic processing in SLI¹²

The ERP technique has been sporadically used to investigate (morpho)syntactic processing in children with SLI. However, the few studies that have been conducted have clearly demonstrated that this population detects syntactic anomalies differently than children with typically developing language (Betz, 2005; Fontaneau & Van der Lely, 2008; Oberecker, 2007; Sabisch, 2007; Sabisch, Hahne, Glass, von Suchodoletz, & Friederici, 2009).

Fontaneau and Van der Lely (2008) found that 12- to 14-year-old children diagnosed with a selective grammatical impairment (G-SLI) do not demonstrate the syntax-related ELAN component (observed in normal age-matched controls) for violations of nonlocal syntactic dependencies (e.g., *Who did Barbie push the clown into the wall?*). As these children showed a semantic N400 component in response to both semantic and syntactic violations, the results were taken as evidence for a selective impairment of grammatical aspects of language processing, while “*a relative strength in semantic processing could be targeted to help compensate for their syntactic impairment*” (Fontaneau & Van der Lely, 2008, p. e1832).

A similar N400-like component has been found by Oberecker (2007). In her study, 32-month-old children at risk for SLI were auditorily presented with easy sentences containing syntactic violations (e.g. *Der Löwe im ___ brüllt [The lion in the ___ roars]*). With respect to their age-matched controls, at-risk children showed an N400 followed by a P600. In particular, when the sample was divided according to the type of linguistic risk (only production vs. production + comprehension) the results changed: the production subgroup only showed the N400-like component, while the production + comprehension group showed both components.

In Sabisch et al.’s studies (Sabisch, 2007; Sabisch et al., 2009), similar violations have been used to test SLI children (mean age 9.8) and age-matched controls (the same syntactic violation paradigm used with DD children and described in Sections 2.4 and 2.5.4). ERPs were recorded while children heard and judged the grammaticality of sentences with a word category violation (syntactic level) and a joined prosodic incongruity (prosodic level). At the behavioural level, SLI children performed significantly worse than control children although their performance was still above chance level. With respect to the ERPs, control children showed a bilateral early starting anterior negativity and a P600 in response to incorrect sentences. SLI children showed a comparable P600 but, unlike controls, there was only a late, clearly left lateralised anterior negativity. The delayed LAN in SLI children suggests that their comprehension processes are not as early as in age-matched controls and do not show the same level of automaticity. Additionally, the

¹² In the present Section only ERPs correlates of morphosyntactic and syntactic processing in SLI will be addressed. Given the fact that the “linguistic nature” of SLI have been extensively demonstrated, a review of the whole literature on linguistic ERPs in SLI is not provided in this dissertation.

complete absence of the RAN component in SLI children suggests that they may not access prosodic information in the same way normal children do.

Finally, Betz (2005) presented two groups of SLI children subdivided according to age with sentences containing overt and omitted finiteness errors (e.g., *Where do a man like to sing?* and *Where a dog like to sit?* respectively). Interestingly, the author found different patterns of performances in the two groups, for what concern behavioural (grammaticality judgement) and ERP responses. While younger SLI children failed in the grammaticality judgement task, and do not show any ERP signature, older SLI children performed at ceiling level in the behavioural task, and showed a large and broadly distributed P600 effect following the syntactic errors. According to the author, the P600 result indicated that for children with SLI whose grammatical deficits may have recently resolved, the related ERP component is larger, perhaps suggesting a heightened awareness of syntactic errors.

2.6 Notes on the use of ERPs to investigate language processing

Based on the overview given in the present chapter, it can be noted that the measurement of ERPs represents an ideal method to study language processing. First, ERPs record the brain's activity time-locked to specific cognitive events millisecond by millisecond, thus providing *excellent temporal resolution* in order to address questions related to the temporal sequence of cognitive events. Given the nature of language comprehension, which also occurs in the human brain in order of milliseconds, ERPs are particularly suited to investigate brain correlates of language mechanisms. It has been noted by many authors that in comparison to other neuroimaging techniques (e.g., fMRI and PET) ERPs have the highest temporal resolution (see Luck, 2005).

Second, ERPs represent a *non-invasive tool suitable to be used with developmental populations*. With respect to other neuroimaging techniques, ERPs are more appropriate to the work with young children. In particular, brain scanning imposes movement restrictions, particularly hard to obtain with children. In addition, there is still open debate on the comparability of the BOLD signal in adults and children (see Männel & Friederici, 2008).

Third, ERPs provide an *on-line recording* of what happens in the brain during language processing, without relying on explicitly requested tasks. They differ from behavioural experiments that measure overt response such as reaction times and number of errors, thus providing us only with the end of the cognitive process.

Finally, as emerged from the review of studies conducted on Developmental Dyslexia, ERPs can be considered *more sensitive as indexes of language processing deficits* than behavioural scores (Rispen et al., 2006; Sabisch et al., 2006; Schulz et al., 2008). This latter point has particularly

motivated the selection of ERPs as tool to investigate subtle morphosyntactic deficit in DD. As emerged in Chapter 1, this thorny question is not easy to be addressed by means of behavioural tasks, and this dissertation is an attempt to address it extensively by means of ERPs.

In spite of these advantages, there are several limitations of the ERP method that should be considered. First, according to Luck (2005, p. 26) the “*single greatest shortcoming*” of ERPs is *spatial resolution*. In comparison to other neuroimaging techniques (e.g., fMRI and PET), the ERPs’ spatial resolution is poorer and undefined. The *inverse problem* denotes the fact that given an ERP pattern, it is not possible to identify the neural generator of the signal, because theoretically there is an infinite number of possible source constellations that could lead to the same scalp distribution. Even the higher amplitude at certain electrodes only provide information about where the neural activity arrives at scalp’s surface.

Second, the *interpretation of the ERPs components* is a very critical issue. Several strategies have been proposed to minimise the problem of ambiguities in interpreting ERPs components. In particular, the use of well-studied experimental manipulations is strongly recommended (Luck, 2005). In addition, combining different measures is another strategy that can minimise ERPs limits. The “Guidelines for using human event-related potentials to study cognition” suggest to always combine ERPs measures with behavioural measures: “*the more behavioural data that are available, the more readily the psychophysiological measures can be evaluated within the context of an information processing model*” (Picton et al., 2000, p. 129).

In the present dissertation the experimental questions proposed in Chapter 1 will be addressed mainly by the ERP technique. The limits of this technique will be however taken into account. In particular, the use of ERPs will be always combined with behavioural techniques. An analysis of similarities and differences between measures will be treated in Chapter 6.

APPENDIX 2A: Summary of the main ERP studies conducted on linguistic components in DD

Authors – Language	Participants	Task	ERP results	Conclusion
Ackerman et al., 1994 (English)	Children diagnosed as dyslexics (IQ discrepancy criteria), poor readers and normal reading children with Attention Deficit Disorder (ADD), 10-year-olds	Rhyme judgement: children were asked to judge whether visually presented word or pseudo-word pairs rhyme	DD children exhibit an attenuated N450 peak, interpreted as an attenuated phonological priming N400 effect)	Non-automatic visual cognitive processing of rhyme in dyslexics
McPherson et al., 1996 (English)	Dyslexic adolescents divided according to phonological skills (visual non-word decoding test): Phonetic DD (better decoders) and Dysphonetic DD (poorer decoders)	Rhyme judgement: adolescents were asked to judge whether two sequentially presented pictures had names that rhymed	Phonetic DD show a normal N400 priming effect, and an additional enhanced negativity (700 to 1000 ms), while dysphonetic DD do not.	Reduction in neural capacity and/or activation during phonological processing in Dysphonetic DD The additional enhanced negativity reflects a higher level of confidence in Phonetic DD
Meyler & Breznitz, 2005 (English)	17 DD and 16 normal college-level readers	Processing of phonological and orthographical word representations	P200 and P300: lower amplitude and delayed latency among DD participants for both type of representations. Group differences were greatest for phonological representations.	Consistent speed-of-processing deficit among participants with DD
McPherson et al., 1998 (English)	16 normal reader adolescents (15,4 ± 0.3) and 16 DD adolescents divided according to phonological skills (visual non-word decoding test): Phonetic DD (better decoders, aged 15,2 ± 0.6) and Dysphonetic DD (poorer decoders, aged 15,4 ± 0.5)	Rhyme judgement: - visual presentation of words varying on the orthographic dimension - auditory presentation of real words	Visual paradigm: Phonetic DD showed both orthographic and phonological priming, while Dysphonetic DD had intact orthographic priming, but reduced phonological priming. Auditory task: Phonetic DD showed a delayed N400 priming effect, while Dysphonetic DD showed a normal N400 priming effect (bilateral)	Separation of the reading disabled into a group that has difficulty translating orthography into phonology (Dysphonetic DD), and a group that is slower functioning and has reduced capacity in preparing for a response (Phonetic DD)
McPherson & Ackerman ,1999 (English)	16 DD adolescents and 16 normal readers (aged 12-18). DD participants divided in according to performance on auditory phonology (Bradley Oddity Task): Phonetic DD (no errors, N = 6) and Dysphonetic DD(errors, N = 10)	Alliteration judgement of auditorily presented single-syllable real-words	Phonetic DD show a normal N400 priming effect (only TCP sites) while Dysphonetic DD show a delayed N400 priming effect	ERP evidence of abnormal phonological functioning and processing speed deficits during auditory phonological processing in reading-disabled participants.

Authors – Language	Participants	Task	ERP results	Conclusion
Bonte & Blomert, 2004 (Dutch)	EXP 1: 12 dyslexic children (8.8±0.7) and 12 control children EXP 2: 12 dyslexic children (8.8±0.65) and 11 control children	Implicit phonological processing (two-word alliteration priming) during spoken word recognition (lexical decision task) EXP 1: words EXP 2: pseudo-words	Absence of an N1 amplitude reduction to alliterating word-word pairs. Normal alliteration priming effects in the N400 TW	Anomaly in phonetic/ phonological processing of spoken words in dyslexic children along with normal word processing at phonological/lexical level
Stelmack et al., 1988 (English)	Normal and disabled readers (RD)	Visual word-recognition task (reading-related task)	RD exhibit: - greater P200 amplitude - lower N400 amplitude - no differences in P300 amplitude	RD are characterised by differences at early sensory stages of item encoding and retrieval, and by less extensive semantic evaluation, not attributable to attentional deficits.
Stelmack & Miles, 1990 (English)	Normal reader and one subtype of disabled readers	Visual presentation of words (preceded by pictures with or without associated meaning)	RD exhibit reduced N400 to unprimed words	This subtype of disabled readers fail in engaging long-term, semantic memory, while their short-term linguistic processing is intact
Johannes et al., 1995 (English)	Six students (aged 19-26) with DD, and 6 control participants	Visual word recognition: effects of word frequency and word recognition	DD students exhibit reduced N400 for high frequency words on their first encounter and no effect of word repetition (amplitudes of the N400) to high frequency words	Dyslexics treat word frequency differently than normal reading controls
Csépe et al., 2003 (Hungarian)	12 university students (19-22) and 3 compensated dyslexic university students (18-19 and 20) reported as additional case studies	Lexical decision paradigm (visual presented words, number-words and pseudo-words)	Both stages of the lexical access are effortful in dyslexic participants, as revealed by the increased P100 and P350.	Dyslexic participants compensates successfully for their reading problems relying on higher-level, more complex therefore high cost processing strategies.
Silva- Pereyra et al., 2003 (Spanish)	16 poor reader children (age 10.2 ± 1.9) and 18 control children (10.1 ± 1.6)	Visual ERP components during figure and word categorisation tasks	Poor reader children had longer and larger P2 amplitudes, and smaller amplitudes and longer P300 latencies than controls, but normal N400 priming effects.	Semantic processing underachievement in PRs may not be a semantic deficit per se, but the late reflection of an early word codification problem, deficient use of attentional resources and lack of target identification during reading.

Authors – Language	Participants	Task	ERP results	Conclusion
Rüsseler et al., 2003 (German)	12 adult with DD and 12 normal readers	Recognition memory task (visually presented words)	Dyslexic adults exhibit normal N400 repetition effect.	
Taroyan, & Nicolson, 2009 (English)	9 dyslexic adolescents (15.6–17.8) and 9 control adolescents (15.4–19.3)	Lexical decision processes during reading words and pseudowords	Dyslexic participants exhibit significantly delayed and attenuated P4 and P5, and no lexical effect, with equal P1 amplitudes for words and pseudowords.	Dyslexics have deficits in pre-lexical visual word form recognition and in the later cognitive processing stages (as shown by slowed and attenuated late ERP components and weaker behavioural performance)
Torkildsen et al., 2007 (Norwegian)	EXP1: 27 typically developing children and 9 children at familial risk of dyslexia (20-month-olds \pm 14 days) EXP2: 17 typically developing children and 9 children at familial risk of dyslexia (24-month-olds \pm 14 days)	Auditory lexical-semantic priming EXP 1: picture/word: congruous and incongruous (within/between category) EXP 2: same/different super-ordinate category	EXP1: At risk children exhibit no N400-like incongruity effect (trend), but enhanced early negativity for words related to the picture, reflecting facilitated lexical processing EXP2: At risk children exhibit delayed N400 incongruity response.	Deficiencies in young children at-risk for dyslexia are not restricted to perceptual and lower-level phonological abilities, but also affect higher order linguistic skills such as lexical and semantic processing.
Helenius et al., 2009 (Finnish)	10 adults with DD (18-25), 10 adults with a history of SLI (18-25) and 13 control adults (18-21)	MEG: neural signatures of auditory word recognition and word repetition	Left hemisphere lexicality effect (N400) present in control and DD adults, but non-significant in the subjects with SLI. The size of the repetition effect decreased from control subjects through DDs to SLIs (200–400 ms)	Impaired short-term maintenance of linguistic activation that underlies word recognition, when advancing from milder to more severe language impairment.
Jednorog et al., 2010 (Polish)	18 children with DD (9.2-11.7) and 18 control children (9.5-10.8).	Auditory phonological priming (words identical in the first 2/3 phonemes) and semantic priming	Semantic priming: DD children exhibit N400 comparable to controls, though delayed. Phonological priming: DD children exhibit reduced N400 amplitude in the incongruent condition, and enhanced N400 in the congruent condition	Existence of phonological deficit in DD (phonological integration and detecting phonological incongruity), while neither integration of semantically congruent features nor detection of semantic incongruity seems clearly impaired. Only the neural processes underlying the former might be delayed.

Authors – Language	Participants	Task	ERP results	Conclusion
Neville et al., 1993 (English)	Children with language impairment and reading problems	Visual sentence comprehension task, sentence with and without semantically anomalous words	Children in the two clinical groups reported an increased N400 effect with respect to control children	Higher reliance on context for comprehension in children with SLI and DD, since they have problems with grammar which impact negatively on language comprehension.
Brandais et al., 1994 (Swiss-German)	12 DD children and 12 control children	Semantic priming: silent reading of sentences with semantically implausible endings	An early segment of the N400 component was parietocentrally less negative for incongruent endings in DD. Moreover, a late segment of the N400 was delayed in DD	Cognitive-linguistic processes are affected in DD children, as revealed by processing delays and qualitatively different patterns of neural activation
Helenius et al., 1999 (Finnish)	DD adults and controls	MEG: Semantically implausible sentences, written presentation	Delayed and attenuated N400 incongruency effects in DD adults, with particularly weaker activation to semantically inappropriate words that began with the same letters as the most expected word	Word recognition by the DD group seems to be qualitatively different: Whereas controls perceived words as wholes, DD participants may rely on sublexical word recognition
Robichon et al., 2002 (French)	DD and control adults	Reading sentences that ended either congruously or incongruously. Visual presentation, one word at a time, at fast (SOA=100 ms) or slow (SOA=700 ms) rates of presentation.	Larger N400 components for dyslexic than control adults, at slow presentation rates, to both congruous and incongruous endings	The reading impairment in DD adults is more likely to result from difficulties integrating the meaning of words within a sentence context than from pure sensory processing deficits
Schulz et al., 2008 (Swiss-German)	16 DD children (11.6±0.3) and 31 control children (11.4±0.4)	ERP & fMRI while children silently read and occasionally judged simple sentences with semantically congruous or incongruous endings	During semantic processing dyslexic children show decreased activation in inferior parietal regions and reduced N400 effect (not reflected in the behavioural results)	Semantic impairment in DD during sentence reading modulates the more sustained BOLD response in left inferior parietal regions
Rösseler et al., 2007 (German)	11 DD adults (19-30) and 11 control participants (19-33)	Semantic, syntactic (gender) and phonological (rhyme) judgement of written word-pairs	The N400 is delayed in the dyslexic group for phonological and syntactic processing, while it persisted longer for the phonological and semantic processing	Dyslexics are phonologically impaired, but they also have difficulties in other non-phonological aspects of reading (semantic and syntactic integration).

Authors – Language	Participants	Task	ERP results	Conclusion
Mody et al., 2008 (English)	15 Poor readers (8-13) and 15 good readers (7-13)	ERP + MEG: Auditory presentation of semantically congruent or incongruent sentences, where critical words could be phonologically similar (PS) (only differing in one phonetic feature) or dissimilar (PD) to the target word. Judgement of semantic plausibility	Poor reader exhibit reduced activation in the PS condition compared to the PD condition in left STG (200-300 ms). No group differences for the N400 latency	Poor reader group misperceived the PS words as congruent with their phonological expectation from the semantic context
Helenius et al., 2002 (Finnish)	9 DDadults (35.6 ± 6.8) and 10 control adults (34.8 ± 4.1)	MEG: auditorily presented sentences, where the sentence-ending words were either semantically appropriate or inappropriate to the preceding sentence context (half of the inappropriate final words shared two or three initial phonemes with the highly expected semantically appropriate words)	Dyslexic participants exhibit an abnormally strong pre-semantic N100 response in the left and a delayed N400 response	The delayed semantic activation is a result of difficulties at the presemantic-phonological stage.
Breznitz, & Leikin, 2000 (Hebrew)	20 Adults with DD (18-27) 20 Control adults	Processing word's syntactic functions during reading of SVO sentences (word by word)	Dyslexic readers exhibited higher amplitude and longer latencies in N100, P300 and N400 amplitude for the "subject" of the sentence.	Dyslexic reader identify words' grammar function in more primitive mode (by means of word order, that although demand more significant effort) while normal readers mostly used a predicate-oriented strategy
Breznitz, & Leikin, 2001 (Hebrew)	20 Adults with DD (18-27) 20 Control adults	Processing word's syntactic functions during reading of SVO sentences (word by word) in two conditions: self-paced and fast-paced presentation)	Dyslexic readers exhibited higher amplitude and longer latencies in N100 and P300 for the self-paced condition, while higher amplitude and shorter latencies in N100 and P300 were found for the fast-paced condition	Beneficial effect of accelerated reading rate on comprehension, realised in the full-usage of word-order strategy.

Authors – Language	Participants	Task	ERP results	Conclusion
Leikin, 2002 (Hebrew)	18 adults with DD (18-27) and 18 control adults	Processing word's syntactic functions during reading of SVO sentences (word by word): effects of syntactic functions and word position	Dyslexic readers exhibited consistently higher amplitudes and longer latencies of P200, P300, and P600 in all sentence elements. The differences in processing the grammatical functions were at least partly caused by their position in the syntactic order.	Processing of words in accordance with their grammatical functions is slower among dyslexic readers and requires more substantial effort. They tend to use word order strategy for processing grammatical functions
Sabisch et al., 2006 (German)	16 dyslexic children (11;1 ± 1;0) and 16 control children (11;1 ± 1;0).	Auditory sentence comprehension (correctness judgement task): - semantic violations (selectional restriction) - syntactic (phrase structure) violation	Delayed Left Anterior Negativity and no Right Anterior Negativity in dyslexic children. No differences have been found between groups concerning the semantic N400 and the syntactic P600	Delay, in DD children, of the early and presumably highly automatic processes of phrase structure building, and of a lack of recognition of the prosodic cues that can facilitate syntactic processing
Rispens et al., 2006 (Dutch)	20 adults with DD (24.1 ± 4.78) and 20 control adults (23.2 ± 3.98)	Auditory presentation of sentences with and without number subject-verb agreement violations (grammaticality judgement task)	The P600 peaks later in the left posterior region in the DD group compared to the control group. In addition, the DD group did not show the P600 in response to sentences with a plural NP subject	Brain activation involved in syntactic repair is more affected by linguistic complexity in DD compared to non-dyslexic individuals

Chapter 3

Study 1:

Morphosyntactic processing in Italian dyslexic adults

3.1 Brief introduction and experimental questions

As we have seen in Chapter 1, the linguistic nature of Developmental Dyslexia is still the object of open debate. Together with the reading difficulties, children with DD show problems involving the linguistic sphere. Phonological difficulties in DD have been definitely demonstrated (Ramus et al., 2003) as well as their causal link to reading difficulties (Snowling, 2000). Semantic, morphological and syntactic skills had not received the same attention, and had only been sporadically investigated. Evidence of weakness in these domains in children and adults with DD are reviewed in Section 1.2.2. In particular, the focus has been on (morpho)syntax, as it represents a “clinical marker” for children with Specific Language Impairment (SLI). The presence of such deficits in DD could thus provide a window on the overlap between the two disorders.

The main question that has been addressed in the present study is:

Is DD characterised by linguistic deficits, mainly involving the morphosyntactic domain?

To answer to this question particularly sensitive measures have been used, namely event-related brain potentials (ERPs). As we have already seen in Chapter 2, this non-invasive method has the great advantage of providing on-line information about linguistic processing with an excellent temporal resolution, thus revealing mild anomalies that cannot be found in behavioural tasks. According to recent neurocognitive models (Friederici, 2002), a bi-phasic electrophysiological pattern (LAN/P600) is normally expected in response to morphosyntactic violations (see Section 2.3). Differences in these electrophysiological patterns have been sporadically reported in Dyslexic

participants, even if linguistic difficulties did not emerge from standardised language comprehension tests (Breznitz & Leikin, 2000; Leikin, 2002; Rispens et al., 2006; Russeler et al., 2007; Sabisch et al., 2006).

Interestingly, only two studies have investigated the ERP responses to the auditory presentation of (morpho)syntactic violations in individuals with DD (see Section 2.5.4).

Rispens et al. (2006) have investigated the presence and latency of the P600 component in response to subject-verb agreement violations in Dutch-speaking adults with DD. Despite the absence of differences between dyslexic and control participants in judging the grammaticality of the sentences, the ERP data revealed subtle differences between groups, particularly related to latency (the P600 tended to peak later in the dyslexic group compared to the control group). Moreover, the dyslexic participants, as a group, did not show the component in response to sentences with a plural subject. This finding was interpreted in relation to the higher complexity of plural with respect to singular forms.

Sabisch et al. (2006) compared the electrophysiological responses to syntactic violations (phrase structure) in German-speaking children (aged 10 to 12) with and without DD. Similarly to Rispens and colleagues, no differences were found in the behavioural task (sentence correctness judgement task). In the ERPs, a similar P600 was found for the syntactic violations. However, instead of the early starting bilaterally distributed anterior negativity shown by control children in response to syntactic violations, dyslexic children presented a delayed left lateralised anterior negativity. This result is discussed in terms of the delay, in dyslexic children, of the early and presumably highly automatic processes of phrase structure building, and of a lack of recognition of the prosodic cues (reflected in control participants' Right Anterior Negativity) that can facilitate syntactic processing.

Although both studies find some anomalies in the ERP responses, their results differ considerably, possibly due to variations in the kinds of violations (subject-verb agreement violations vs. phrase structure violations), in ERP analyses (peaks vs. mean amplitude) and in the dyslexic population under examination (adults vs. children). Thus, further ERP studies seemed to be necessary in order to put on a solid basis the view that persistent language deficits may be present in dyslexic individuals.

While differences in the sensitivity to phrase-structure building violations among languages are not expected, differences in subject-verb agreement violations may be expected due to the language specific features. In fact, Italian, compared to Dutch, is a language with a richer and more regular verbal agreement morphology and this may affect DD participants' sensitivity to subject-agreement violations. Additionally, verbal plural agreement forms are often considered one of the clinical

markers for SLI (Bortolini et al., 1997), and subject-verb agreement provides a well proved paradigm to be tested electrophysiologically. As this paradigm has been widely used with healthy populations in different languages (Coulson et al., 1998; Hagoort et al., 1993; Osterhout & Holcomb, 1995; Rossi et al., 2005) among which Italian (Balconi & Pozzoli, 2005; De Vincenzi et al., 2003), it provides a strong starting point for the study of clinical populations.

In the present study, we used this electrophysiological paradigm in order to investigate morphosyntactic processing in DD adults. Based on reported data from non-impaired populations, the typical bi-phasic electrophysiological pattern (LAN/P600) was expected in the control participants. Two main points were addressed concerning the dyslexic group:

- a) *Presence/absence of the typical ERP components associated with morphosyntactic violations (LAN/P600)*
- b) *Differences with respect to control participants concerning mean amplitude and/or latency and/or lateralisation*

Moreover, based on Rispens et al.'s (2006) results, differences concerning the processing of singular and plural verbal forms were also expected in light of the ascertained additional complexity of plural with respect to singular. Being verbal plural agreement forms a clinical marker in SLI, electrophysiological anomalies in DD in response to these forms were also expected in light of the hypothesised overlap between the two disorders.

- c) *Differences concerning the NP subject number as expected on the basis of previous studies*

Particular attention was devoted in the present study to the recruitment and selection of the dyslexic participants, for which retrospective data (both diagnoses and medical records) were available. They were all adults who had received a formal diagnosis of Developmental Dyslexia during childhood, but had no report of language impairments. Moreover, at the moment of testing, both language and reading skills were re-assessed, and all the dyslexic participants still showed significant deficits in reading but not in language skills.

3.2 Method

3.2.1 Participants

Sixteen young adults with Developmental Dyslexia (ranging in age between 19 and 27 years, 4 females) and 16 control participants matched for gender and age participated in the study. All participants were volunteers and an informed consent to take part in the study was obtained after the purpose and procedures of the study were explained. The study was approved by the Ethics Committee of the Institute “E. Medea”, according to standards of the Helsinki Declaration (1964).

Participants with Developmental Dyslexia had been referred to the Unit of Cognitive Psychology and Neuropsychology because of learning difficulties during childhood, and had been diagnosed as dyslexics based on standard exclusion criteria by an expert clinician (ICD-10; World Health Organization, 1992). All participants were Italian native speakers, and had normal or corrected-to-normal vision and normal hearing. The non-verbal or performance IQ at time of the last formal clinical assessment - estimated by the Wechsler Intelligence Scale for Children-revised (WISC-r; Wechsler, 1994) [$n = 5$], or Cattell’s ‘Culture Free’ (Cattell, 1979) [$n = 10$], or Raven’s Advanced Progressive Matrices (Raven, 1998) [$n = 1$] - was above 85 for all the participants. None of the dyslexic participants had a previous diagnosis of language impairment or a history of speech and language therapy. Moreover, at the moment of testing the absence of a formal language disorder was further confirmed by a standardised test (BAT; Paradis, 1987). All the dyslexic participants were still impaired in reading skills, as assessed by a battery including word, non-word and text reading. Their performance was still two standard deviations below the norms in at least one of the standardised Italian reading tests included in the battery. All dyslexic participants were right-handed.

Control Participants were selected to match each participant in the dyslexia group on gender and chronological age. Moreover, due to the fact that the dyslexic participants had different degrees of school instruction (ranging from vocational school to university), the control participants were also selected on the basis of their education. All the control participants performed normally on a standardised Italian text reading task, providing accuracy and speed scores in reading aloud (Judica & De Luca, 2005), according to norms based on educational level (distinguishing between high school and university). All the control participants were right-handed.

Between dyslexic and control participants, there was no group difference in age (dyslexic participants: $M = 22.67$, $SD = 2.29$; control participants: $M = 22.36$, $SD = 3.48$; $t(30) = -0.300$; $p =$

.767). As expected, a significant difference was found between Z-scores in the reading test concerning both speed (dyslexic participants: $M = -20.22$, $SD = 33.66$; control participants: $M = -0.807$, $SD = 1.99$; $t(15.153) = 2.301$; $p < .05$) and accuracy (dyslexic participants: $M = -3.12$, $SD = 1.77$; control participants: $M = 0.6445$, $SD = 0.64$; $t(20.207) = 7.808$; $p < .001$).

3.2.2 Behavioural assesement

Concerning **reading skills**, the following tests were administered:

- Text reading: ‘Nuove prove di lettura MT per la scuola media inferiore’ (New Reading tests for secondary school; Cornoldi & Colpo, 1995), developed by the MT group: widely used Italian tests providing accuracy and speed scores in reading aloud age-normed texts. In particular, z-scores were computed for speed and accuracy, according to the norms for the 3rd (last) secondary school grade. ‘Prova di velocità di lettura di brani per la Scuola Media Superiore’ (Text reading speed test for high school; Judica & De Luca, 2005): an Italian test providing accuracy and speed scores in reading aloud texts. Norms are available both for high school students and for university students. According to the appropriate norms, z-scores were computed for speed and accuracy.

- Word and non-word reading: Batteria per la valutazione della dislessia e disortografia (Battery for the assessment of Developmental Reading and Spelling Disorders; Sartori, Job, & Tressoldi, 1995): an Italian reading and spelling assessment battery. Speed and accuracy z-scores were computed for single word and non-word reading.

Phonemic awareness was assessed with three tasks taken from a battery with unpublished but wide and consistent normative data. In all the tasks the experimenter provided an auditory presentation of non-words, and different types of explicit manipulations were requested (oral answers required):

- Syllabic manipulation: moving the last syllable of a non-word at the beginning of the same non-word (for example: ‘cu-sto-ne’ should become ‘ne-cu-sto’).

- Spoonerisms: swapping the initial phonemes of two one-syllable auditorily presented non-words (for example: ‘des’ and ‘mag’ should become ‘mes’ and ‘dag’).

- Phoneme synthesis: integrating sequentially, auditorily presented phonemes into non-words (for example: l-e-m should become ‘lem’).

For each task, z-scores were computed for speed and accuracy.

Verbal short-term memory was assessed by a monosyllabic non-word span test, a subtest of the same unpublished battery used for phonemic awareness. Participants had to repeat forwards the orally presented lists of one-syllable non-words, increasing in number (for example ‘caf – nab’).

Language skills were assessed through the Bilingual Aphasia Test (Paradis, 1987), a standardised test providing a detailed analysis of language proficiency at different linguistic levels (phonology, morphology, syntax, lexicon and semantics). It was originally created to assess language abilities in bilingual aphasics, but part B of the test provides information about linguistic competence in the main language. Normative data for Italian are provided. Seven of the 32 subtests were selected, in order to investigate syntax (‘Syntactic comprehension’ and ‘Grammatical judgement’ tasks), morphology (‘Derivational morphology’ and ‘Morphological opposites’ tasks), and auditory comprehension skills (‘Verbal auditory discrimination’, ‘Repetition of sentences’ and ‘Listening comprehension’ tasks).

3.2.3 Experimental task

3.2.3.1 Material

After an accurate inspection of the ERPs studies on subject-verb agreement violations, 168 simple Italian sentences were expressly created, including a noun phrase (NP) subject, a present tense main verb and an adjunct phrase (see appendix A). Half of the sentences had a singular NP subject, and half had a plural NP subject. For each sentence an incorrect form was created, changing the number of the main verb. Table 3.1 shows a sentence example for each experimental condition, where both ‘Grammaticality’ and ‘Subject Number’ were manipulated.

Grammaticality	Subject Number	Examples
Correct	Singular	La bambina bionda (S) gioca (S) con la palla [<i>the blond child (S) plays (S) with the ball</i>]
Incorrect	Singular	*La bambina bionda (S) giocano (P) con la palla
Correct	Plural	I delfini svegli (P) saltano (P) sulle onde [<i>the cute dolphins (P) jump (P) over the waves</i>]
Incorrect	Plural	*I delfini svegli (P) salta (S) sulle onde

Table 3.1: Examples of stimuli

All verbs were intransitive, or could be employed intransitively. The nouns and adjectives of the NP subjects were also carefully selected. They all were bi-syllabic or three-syllabic and in order to

avoid potential ambiguous endings, the final vowel of both the noun and the adjective was always the unmarked one (-a or -o for singular and -e or -i for plural; singular nouns and adjectives ending with -e were avoided). In order to keep the experimental sentences as varied as possible, sex (male and female) and animacy (humans, animals and inanimate objects) of the NP subjects varied across sentences. These two variables were controlled within the experimental paradigm, but they were not entered as experimental variables. Moreover, each verb was used twice, but with different NP subjects, and always in different ‘Grammaticality’ conditions (once correct and once incorrect). In this way, exactly the same verbs were presented in the two conditions, thus allowing to avoid differences (with respect to verb length, conjugation, frequency, concreteness etc.) between conditions. Furthermore, all verbs to be used in the two Subject-Number conditions were individually matched for length, conjugation and frequency (for example ‘giocare’ [to play] and ‘saltare’ [to jump]) before being assigned to the two conditions. Due to the fact that the same sentences had to be used for another study involving children (see Chapter 4), all the words (nouns, adjectives and verbs) were selected from a database providing frequency of occurrence for children (Marconi, Ott, Pesenti, Ratti, & Tavella, 1993). A plausibility judgement task was performed before starting the ERP experiment, in order to avoid semantic implausibility, that could result in different ERP components. The correct sentences were then rated as ‘semantically plausible’ (along a 5-point Likert scale) by 12 native speakers of Italian that did not take part in the following part of the experiment (ranging in age between 18 and 40 years).

In addition to the 168 experimental sentences, 32 filler sentences with a different structure and type of violation were created. These additional sentences were formed by a proper or common name, a verb in the past tense (auxiliary + past participle) and an adjunct phrase (“Francesca è caduta dalla sedia” [*“Francesca fell down from the chair”*] or “Monica ha bussato alla porta” [*“Monica knocked at the door”*]). Pure ergative or inergative verbs were used, and the violation was constituted by the wrong choice of the auxiliary (* “Francesca ha caduto dalla sedia” or * “Monica è bussata alla porta”). For these filler sentences the ERP were not recorded, but the behavioural data (grammaticality judgement task) are available.

All sentences were spoken by two female native speakers of Italian. They were previously trained to normalise the acoustic pitches, and they were instructed to pronounce the sentences with natural sentence prosody. They were also asked to avoid coarticulation between the words by inserting a short pause into the speech stream (between NP subject and verb, and between the verb and the adjunct phrase). The sentences were then recorded into a silent cabin through the software ‘Praat’. The recordings were then digitalised at a sampling rate of 44.1 kHz (16 bit; stereo). The two speakers pronounced the same number of sentences for each condition. Every sentence was

pronounced twice, once with a singular verb, and once with a plural one. Moreover, half of the sentences were pronounced correctly and half were pronounced incorrectly, and the incorrect or correct versions were created by a ‘splicing procedure’, where only the verb of the sentence was changed. In this way, half of the correct and half of the incorrect sentences presented in the experiment were the original recorded sentences, while the remaining sentences had been digitally modified.

Participants were presented with each sentence only once (in the correct or incorrect version). To this purpose, two lists differing only in ‘Grammaticality’ were created, and each individual was presented with only one list. Two pseudo-randomised lists were created so that no more than two items of the same ‘Grammaticality’ (correct vs. incorrect), and ‘Subject Number’ (singular vs. plural) conditions were presented in a row, and no more than three items uttered by the same speaker, created with the same modality, and with NP subjects of the same sex or animacy (human, animal or inanimate objects) were presented in a row. Six blocks were created, each containing 28 experimental items and 5 or 6 fillers. The lists and the blocks were counterbalanced across participants to avoid order effects. Participants were assigned to a list pseudorandomly and presentation of the two lists was comparable between the two groups.

The stimuli were stored on a pc and presented using STIM2 software package (Neuroscan) via headphones (Sennheiser HD270), at a comfortable volume of 80 dB. In addition to the 168 experimental sentences, 32 filler sentences with a different structure and type of violation were created and presented.

3.2.3.2 Task-specific procedure

During the experiment, participants listened to the sentences in a quiet room with dimmed lighting and were seated in a comfortable chair 1 m away from the computer monitor. They were instructed to listen carefully to the sentences, in order to judge their grammaticality. Figure 3.1 shows one exemplary trial. First, a fixation star appeared in the centre of the monitor for 500 ms. Then, the acoustic presentation of the sentence started, and the fixation star remained on the monitor until 500 ms after the offset of the sentence. Participants were requested to fixate on the star and to avoid eye blinks and movements. Each sentence was presented divided into three blocks, so that fixed pauses compatible with a natural sentence prosody were created between NP subject and verb (150 ms) and between verb and adjunct phrase (100 ms). After the last block offset, there was an additional break of 500 ms to prevent any movement elicited by the button press interfering with ERP recording. It was estimated that a longer pause was not necessary, because between the critical word (verb) and the requested movement, the whole adjunct phrase (with a mean duration of

about 1200 ms) additionally elapsed. After the break, a sound and a little face were presented, and participants were instructed to judge the grammaticality of the sentence by pressing one of two buttons on a response box. Stickers of a thumb-up and a thumb-down, respectively corresponding to ‘correct’ and ‘incorrect’, were attached to the buttons on the response box. There was no maximum response time, and the next trial started immediately after the response. Before the experiment started, 12 practice trials were provided to familiarise the participant with the task. Differently from visual presentation, the auditory presentation of the sentences allows very accurate time-locking of the ERP. In the present experiment, ERP were time-locked both to the beginning of the critical word (verb) and to the beginning of the critical morpheme (gio’ca vs. gio’cano), but only the ERP derived by this latter time-locking will be presented.

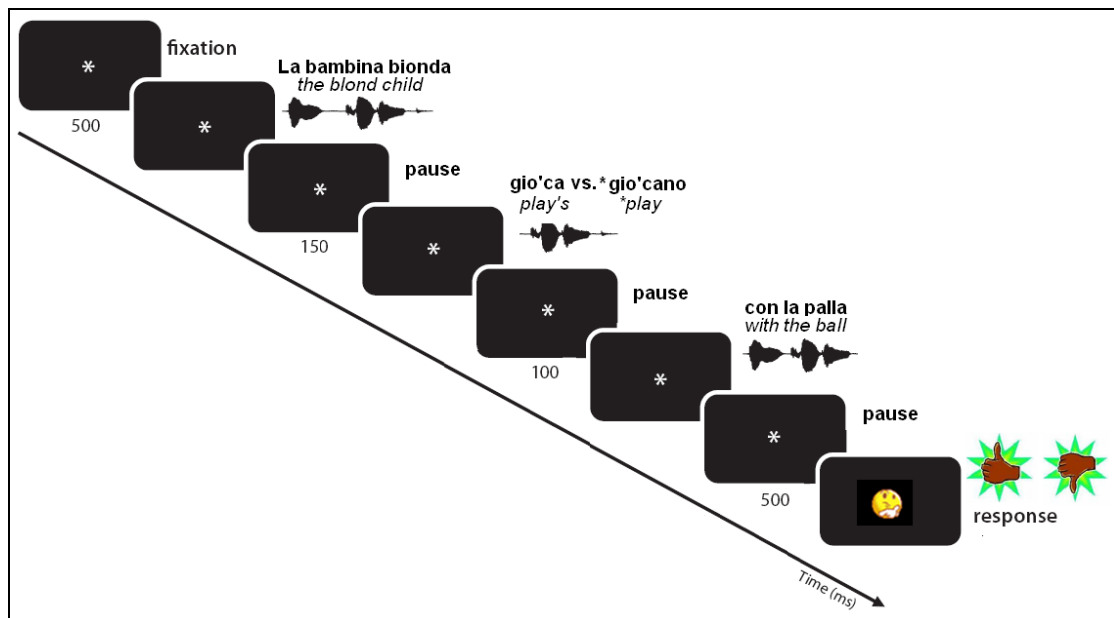


Figure 3.1: Sequence of events per trial, including timing, visual input, and task requirements.

3.2.3.3 ERP data acquisition:

Electroencephalogram (EEG) was recorded from 15 Ag/AgCl electrodes placed according to the international 10-20 system at the following positions: F7/8, F3/4, Fz, T7/8, C3/4, Cz, P3/4, Pz, O1/2. Blinks and vertical eye movements (VEOG) as well as horizontal eye movements (HEOG) were recorded from two electrodes, located below and lateral to the left eye. EEG signals were recorded with the average of the right and left mastoid as reference. An electrode placed on the participant’s forehead served as ground. All electrodes impedances were kept below 5 k Ω . All electrodes were connected to a Neuroscan amplifier (SynAmps vers. 1, Compumedics). The electrophysiological signals were digitalised at the rate of 1000 Hz and offline bandpass zero-phase

filtered (1-40 Hz). The continuous EEG signal was then treated with an automatic rejection criterion applied to all the electrodes (sections exceeding 70 μ V were excluded). All ERPs were time-locked to the onset of the critical morpheme, and calculated with respect to a baseline (covering the 100 ms prior to this point) for an epoch of 1200 ms.

3.2.4 General procedure

Standardised tests and experimental tasks were both conducted individually in laboratories of the scientific institute. The experimental task lasted approximately 45 minutes, and additionally 30-45 minutes were necessary to prepare the participant for the EEG recording. The standardised tests were performed in the same session, after a long break. Control participants were administered only the text reading test (Judica & De Luca, 2005), while dyslexic participants were administered the whole battery. This resulted in a two-hour long session for control participants, and a three-hour long session for the dyslexic participants.

3.3 Results

3.3.1 Behavioural Results

3.3.1.1 Grammaticality judgement task

All participants performed above chance level in the grammaticality judgement task. The results are presented in Figure 3.2. Two separate repeated measure analyses of variance (ANOVAs) were performed, one for the experimental sentences (containing subject-verb agreement violations) and one for the filler sentences (containing violations in the choice of the auxiliary). In both ANOVAs the between-subject factor Group (control participants vs. DD participants) and the within-subject factor Grammaticality (correct vs. incorrect) were defined for analysis

The ANOVA concerning experimental sentences yielded a main effect of Group, $F(1,30) = 4.70$, $p < .05$, with fewer correct responses for the dyslexic group ($M = 97.95$, $SD = 1.83$) compared to the control group ($M = 99.03$, $SD = 0.78$). Moreover, a main effect of Grammaticality emerged, $F(1,30) = 13.82$, $p = .001$, showing a general better performance in judging the incorrect sentences ($M = 99.22$, $SD = 1.19$) than the correct sentences ($M = 97.77$, $SD = 2.32$). The interaction Grammaticality * Group was however not significant, $F(1,30) = 0.08$, $p > .05$, revealing a similar pattern of

performances in the two groups¹³.

The analysis concerning filler sentences yielded only a main effect of Group, $F(1,30) = 4.29$, $p < .05$, again with fewer correct responses for the dyslexic group ($M = 96.09$, $SD = 4.34$) compared to the control group ($M = 98.63$, $SD = 2.27$). However, nor Grammaticality or Grammaticality * Group reached statistical significance ($F(1,30) = 4.29$, $p < .05$ and $F(1,30) = 4.29$, $p < .05$, respectively).

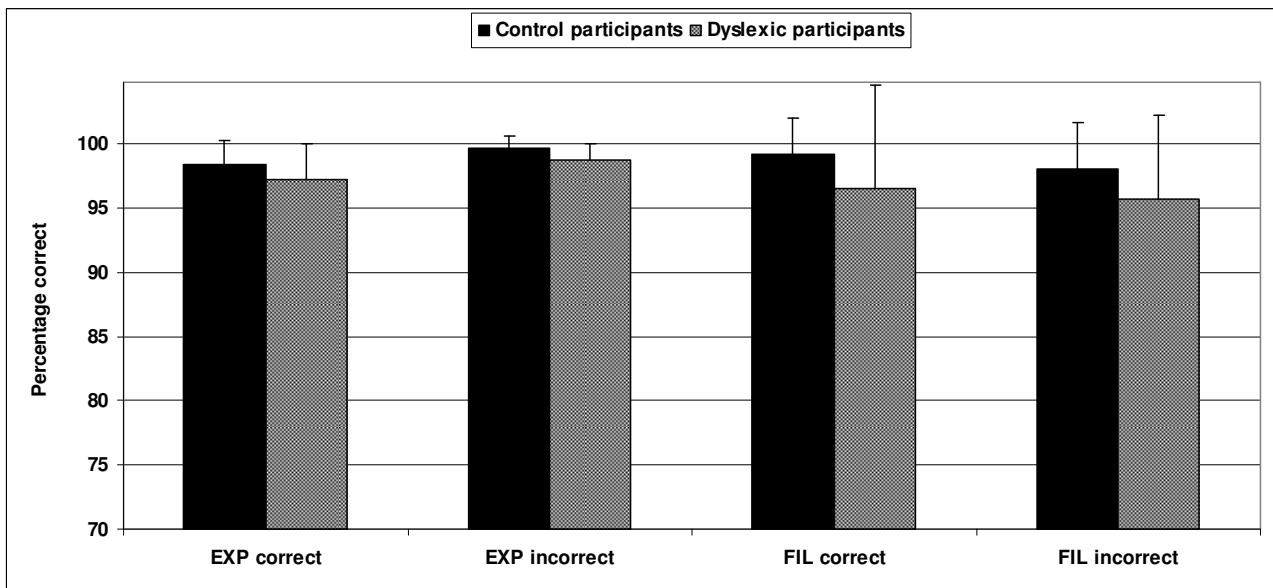


Figure 3.2: Percentage of correct answers in the grammaticality judgement task

Although a difference between groups emerged in both sets of analyses, it should be noted that the accuracy was extremely high in both groups. In order to quantify the presence of difficulties in judging the grammaticality of sentences in the dyslexic group, the distribution of scores in the control group was taken as a reference. It could be observed that in the experimental sentences 37,5% of dyslexics ($n = 6$) obtained scores 2 SD below the mean of controls, whereas an additional 25% ($n = 4$) obtained scores within 1 and 2 SD. Similarly, in the filler sentences 37,5% of dyslexics ($n = 6$) obtained scores 2 SD below the mean of controls, whereas no one obtained scores within 1 and 2 SD. It seems, thus, that at least half of the dyslexic participants had difficulties in the task with respect to controls.

¹³ In order to investigate the effect of the number of the subject on the participants' performances, additional analyses were performed for the experimental sentences. In particular, a repeated measure ANOVA was performed, with Grammaticality and Subject Number (singular vs. plural) as within-subject factors and Group as between-subject factor. Only the main effects of Grammaticality ($F(1,30) = 12.92$, $p < .001$) and Group ($F(1,30) = 5.15$, $p < .05$) emerged, while no main effect of Subject Number and no interactions emerged (all $p_s > .05$). As this result suggests, both control and dyslexic participants seem to judge the grammaticality of singular and plural sentences with the same accuracy.

3.3.1.2 Correlations between behavioural measures

Only for the dyslexic group, Pearson correlations between the percentages of correct answers in the grammaticality judgement task and the scores in reading, reading related and language tests were also performed. Two variables concerning the grammaticality judgement task were entered in the analysis (correct and incorrect). For the language test (BAT), only the score on the subtest 'Syntactic comprehension' and a composite score named 'Morphology' (mean of two subtests of the BAT test: 'Derivational morphology' and 'Morphological opposites') were entered in the analysis. For reading and reading-related tests no composite scores were created, and all the z-scores for each task (text reading and words and non-words reading) and subtest (Syllabic manipulation, Spoonerisms and Phoneme synthesis) concerning both speed and accuracy were entered in the analysis, resulting in a total of 8 variables for reading (text reading: MT speed, S. Lucia speed, MT accuracy, S. Lucia accuracy; words reading: speed and accuracy; non-words reading: speed and accuracy) and 6 variables for phonemic awareness (Syllabic manipulation: speed and accuracy; Spoonerisms: speed and accuracy; and Phoneme synthesis: speed and accuracy). Correlations were found between the Syntactic comprehension subtest of the BAT and accuracy in the judgement of incorrect sentences ($r(16) = 0.662, p = .005$). Speed in the Spoonerism task was also related to the judgement of the incorrect sentences ($r(14) = 0.623, p = .017$), but due to the high number of correlations performed, this latter value cannot be considered statistically significant.

3.3.2 Electrophysiological Results

The ERP data for the incorrect versus the correct condition are displayed in Figure 3.3. The subject-number agreement violation displays in both groups a broad positive wave, which can be interpreted as a P600. The wave is similar in amplitude for dyslexic and control participants, but it seems to be delayed in the dyslexic group. Partially in contrast to expectations and previous results, no Left Anterior Negativity seems to emerge. However, an early negativity (peaking around 300 ms) broadly diffused all over the scalp is shown in the dyslexic group only.

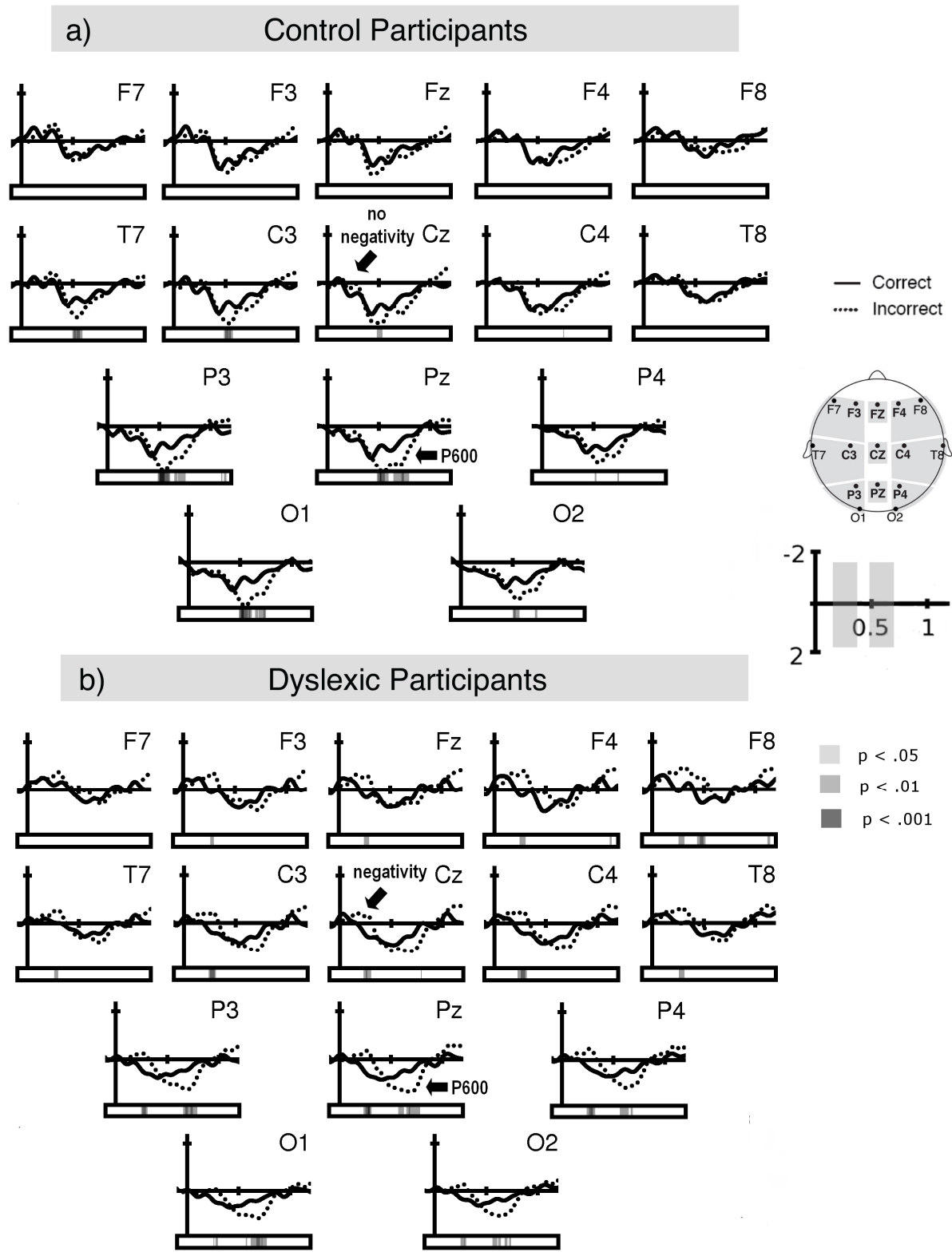


Figure 3.3. Grand average ERPs of the control (a) and dyslexic (b) participants. The morpho-syntactically incorrect condition (dot line) is plotted against the correct condition (continuous line). The axis of the ordinates indicates the onset of the suffix. The grey sections refer to statistically significant t-test performed on picks. Negative voltage is plotted upward. The plots have been filtered with a 7-Hz low-pass filter for presentation purpose only.

3.3.2.1 Data analysis

Two Time Windows (TWs) were selected, according to the literature and after an accurate inspection of the Grand Averages: 150-350 and 450-850 ms. Separate repeated measure ANOVAs concerning the ERP mean amplitude were performed for each TW. The between-subject factor Group (dyslexic participants vs. control participants) and three within-subject factors (Grammaticality: correct vs. incorrect; Hemisphere: left vs. right; Region: anterior vs. central vs. posterior) were defined for analysis of data from 12 lateral electrodes. The variables Hemisphere and Region were completely crossed, yielding six Regions of Interest (ROIs), each of which had two electrodes: Left Anterior (F7 and F3), Right Anterior (F4 and F8), Left central (T7 and C3), Right Central (C4 and T8), Left Posterior (P3 and O1) and Right Anterior (P4 and O2). Additionally, separate analyses were performed for the three midline electrodes (Fz, Cz and Pz). Again, separate repeated measure ANOVAs concerning the ERP mean amplitude were performed for each TW. In this case, the between-subject factor Group and two within-subject factors (Grammaticality and Region) were defined for analysis.

The latter TW (450-850 ms), typically associated with the P600 component, was further analysed, in order to determine the onset of the component, and to detect possible differences between the two groups. In particular, the P600 latency was computed with the single-subject approach subtracting the ERP responses to grammatical sentences from the non-grammatical ones. *The fractional area* technique (Luck, 2005) was used to define the latency of the component as the first time point at which a certain percentage of the total area has been reached. As suggested by Kiesel, Miller, Jolicoeur and Brisson (2008) the component area to be reached was set at 30%, and a slightly positive boundary was defined (2% of the peak of the non-grammatical phrases, maximum peak) in order not to include any negative values in the area. A repeated measure ANOVA was thus performed, where the between-subject factor Group and two within-subject factors (Region and Hemisphere) were defined for analysis. This analysis, as well as the next one, were performed on lateral electrodes only, given the absence of differences between lateral and midline electrodes in the main analyses.

Finally, two further ANOVAs were performed in the two TWs (150-350 and 450-850 ms) involving the within-subject factor Subject Number (singular vs. plural), resulting in a 2 (Group) x 2 (Grammaticality) x 2 (Subject Number) x 2 (Hemisphere) x 3 (Caudality) design.

3.3.2.2 Time-window 150-350 ms

The results of the main analyses concerning lateral electrodes are reported in Table 3.2. A main effect of Grammaticality emerges, indicating the presence of a statistically significant component, that is neither left lateralised nor anteriorly located. Interestingly, interactions involving the between-subject factor Group approached statistical significance, and the 4-way interaction Grammaticality * Group * Hemisphere * Region reached it.

	Df	F	p-value
Grammaticality	1,30	7.295	< .05
Gram.* Hemisphere	1,30	< 1	
Gram.* Region	2,60	< 1	
Group	1,30	1.827	.18
Group * Grammaticality	1,30	1.796	.19
Gram. * Group* Hem.	1,30	2.895	.09
Gram. * Group* Reg.	2,60	<1	
Gram. * Group * Hem. * Caud.	2,60	7.304	<.005

Table 3.2: Global analyses of ERP data at lateral electrodes (TW 150-350)

According to these results, and to the visual inspection of the Grand Average, which also suggests differences between groups, further analyses in this time-window were performed. Separate ANOVAs for groups revealed a main effect of Grammaticality only in the dyslexic group, $F(1,15) = 6.18$, $p < .05$, and not in the control group, $F(1,15) = 1.36$, $p > .05$. Moreover, separate analyses for ROIs are shown in Table 3.3. The main effect of Grammaticality never reached statistical significance for the control group. However, the effect was significant for the dyslexic group, especially in the posterior areas, both left and right. Due to this generalised distribution of the component, it cannot be interpreted as a classical LAN.

	Control Participants			Dyslexic Participants	
	df	F	p-value	F	p-value
Left Anterior	1,15	1.538	.23	1.780	.20
Rigth Anterior	1,15	<1		3.698	.07
Left Central	1,15	3.698	.07	5.462	<.05
Rigth Central	1,15	<1		7.035	<.05
Left Posterior	1,15	2.929	.11	7.064	<.05
Rigth Posterior	1,15	1.815	.20	8.061	<.01

Table 3.3: Separate analyses for dyslexic and control participants in the six ROIs for the TW 150-350 ms

The same analysis was repeated at midline electrodes. The results, reported in Table 3.4, revealed again a main effect of Grammaticality. The absence of significant interactions, however, prevents from performing further analyses.

	df	F	p-value
Grammaticality	1,30	7.822	< .01
Gram.* Region	2,60	< 1	
Group	1,30	1.406	.245
Group * Grammaticality	1,30	1.718	.20
Gram. * Group* Reg.	2,60	<1	

Table 3.4: Global analyses of ERP data at midline electrodes (TW 150-350)

3.3.2.3 Time-window 450-850 ms

The results of the main analyses are reported in Table 3.5. A main effect of Grammaticality emerges. Moreover, the significant interaction with Region indicates the existence of a component differently distributed on the scalp. Paired t-tests were then performed to compare correct and incorrect conditions at different regions, revealing that the component was mainly localised at Central, $t(31) = -2.57$; $p < .05$, and Posterior regions, $t(31) = -5.37$; $p < .001$, but not at Anterior regions, $t(30) = -0.11$; $p > .05$. Additionally, a main effect of Group emerged, indicating substantial differences between the groups.

	Df	F	p-value
Grammaticality	1,30	7.754	<.01
Gram.* Hemisphere	1,30	3.794	.06
Gram.* Region	2,60	26.454	<.001
Group	1,30	4.762	<.05
Group * Grammaticality	1,30	<1	
Gram. * Group* Hem.	1,30	<1	
Gram. * Group* Region	2,60	<1	
Gram. * Group * Hem. * Reg.	2,60	2.167	.13

Table 3.5: Global analyses of ERP data at lateral electrodes (TW 450-850)

The same analysis was repeated at midline electrodes, showing a similar pattern (the results are reported in Table 3.6). A main effect of Grammaticality and the interaction Grammaticality * Region emerge. Again, paired t-tests comparing correct and incorrect conditions at different electrodes reveal that the component was significant only at Central, $t(31) = -3.32$; $p < .005$ and Posterior

regions, $t(31) = -5.49$; $p < .001$, but not at Anterior regions, $t(30) = -1.17$; $p > .05$.

	df	F	p-value
Grammaticality	1,30	12.02	< .005
Gram.* Region	2,60	20.51	< .001
Group	1,30	2.82	.103
Group * Grammaticality	1,30	<1	
Gram. * Group* Reg.	2,60	<1	

Table 3.6: Global analyses of ERP data at lateral electrodes (TW 450-850)

After inspection of the Grand Averages, further analyses were performed in this time window, in order to check for latency differences between groups. Latencies were computed through a *fractional area technique* (Luck, 2005). The time point at which the 30% of the total area of the component (defined as the difference wave) was reached, was calculated for every participant in the six ROIs. A main effect of Group emerged, $F(1,30) = 5.822$, $p < .05$, showing a general delay of about 50 ms in the dyslexic group (dyslexic participants $M = 0.667$, $SD = 0.068$; control participants: $M = 0.611$, $SD = 0.062$). Additionally, a main effect of Region, $F(2,60) = 4.638$, $p < .05$, and a significant interaction Region * Group, $F(2,60) = 3.793$, $p < .05$, emerged, showing broader differences between groups at central regions, $t(30) = 2.30$; $p = .001$, with respect to anterior, $t(30) = -2.12$; $p < .05$, and posterior, $t(30) = -0.37$; $p > .05$, ones.

3.3.2.4 Number manipulation:

Further analyses were performed taking into account the within-subject factor Subject Number. Although the behavioural results failed to reveal any differences concerning this variable (see Section 3.3.1.1), it has an influence on the ERP data, in both the analysed TWs (150-350 and 450-850; see Table 3.7).

	df	TW 150-350		TW 450-850	
		F	p-value	F	p-value
Number	1,30	< 1	.282	<1	
Gram.* Number	1,30	< 1		6.203	<.05
Gram.* Number * Group	1,30	11.411	<.005	5.404	<.05

Table 3.7. Analyses of ERP data for dyslexic and control participants taking into account the “Subject Number” manipulation

A three-way interaction (Grammaticality * Number * Group) emerged in the first TW (150-350 ms), as illustrated in Figure 3.4. In both groups, the two-way interaction Grammaticality * Number reached statistical significance (control group: $F(1,15) = 4.838, p < .05$; dyslexic group: $F(1,15) = 6.667, p < .05$), but with a completely different pattern. In the control group the electrophysiological response to the incorrect sentences differ from the response to the correct ones only in the singular condition, $t(15) = 3.216, p < .01$, while in the dyslexic group the difference emerges only in the plural condition, $t(15) = 4.050, p = .001$.

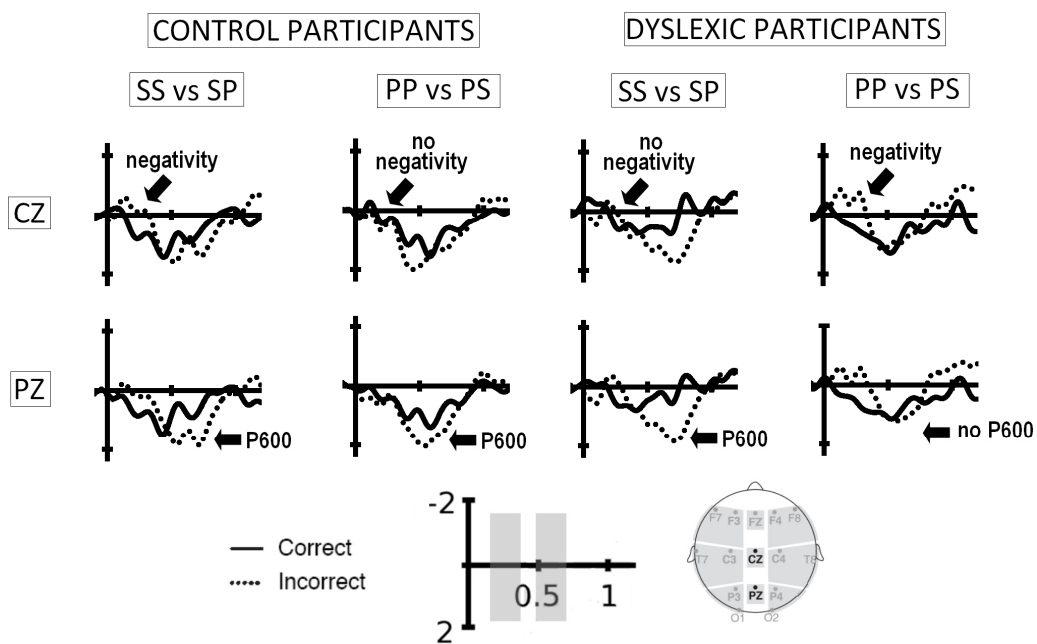


Figure 3.4 Grand average ERPs, separated according to the “Subject Number” manipulation (limited to CZ and PZ electrodes). The morpho-syntactically incorrect condition (dotted line) is plotted against the correct condition (solid line). The axis of the ordinates indicates the onset of the critical morpheme. Negative voltage is plotted upward. The plots have been filtered with a 7-Hz low-pass filter for presentation purpose only

In the second TW (450-850 ms) both the two-way (Grammaticality * Number) and the three-way interactions (Grammaticality * Number * Group) were significant (see Table 3.7). When performing separate analyses for each group, the two-way interaction Grammaticality * Number reached statistical significance only in the dyslexic group, $F(1,15) = 8.474, p < .05$. As illustrated in Figure 3.4, a difference between the electrophysiological responses to correct and incorrect sentences in the dyslexic group emerged only in the singular condition, $t(15) = -2.698, p < .05$. Differently, in the control group, no differences emerged in the way singular and plural are processed (Grammaticality * Number: $F(1,15) = .022, p > .05$).

3.3.3 Correlations between ERP and Behavioural data

In order to compute Person correlations between electrophysiological responses and behavioural data (both experimental and standardised tasks), electrophysiological difference values were created, subtracting the mean amplitude of correct sentences from the mean amplitude of incorrect sentences in the six ROIs. For the behavioural data, the variables previously entered in the behavioural correlations were used. No correlations were found with the negativity in the TW 150-350 ms. However, in the TW 450-850 correlations were found between electrophysiological results and reading tasks. In the whole sample negative correlations were found between reading speed (z-scores) in text reading and electrophysiological difference values in two of the six ROIs (Central Left: $r(27) = -0.444$, $p = .020$; Posterior left: $r(27) = -0.426$, $p = .027$). When considering only the dyslexic group, the same correlations emerged (Central Left: $r(16) = -0.566$, $p = .022$; Posterior left: $r(27) = -0.631$, $p = .009$). Interestingly, similar correlations with reading speed were only found in the dyslexic sample when considering the other text reading test (MT) (Central Left: $r(16) = -0.534$, $p = .033$; Posterior left: $r(16) = -0.708$, $p = .002$), and with reading speed and accuracy in word and non-word reading (Central Left with speed in non-word reading: $r(16) = -0.529$, $p = .035$; Posterior Left with speed in word reading: $r(16) = -0.626$, $p = .009$; with accuracy in word reading: $r(16) = -0.556$, $p = .025$; with speed in non-word reading: $r(16) = -0.710$, $p = .002$; with accuracy in non-word reading: $r(16) = -0.610$, $p = .012$). Contrary to expectations, the direction of these correlations means that broader positivities are associated with worse reading scores. No other significant correlations emerged, neither with experimental tasks, nor with language standardised tests and reading-related ones.

3.4 Discussion

The main aim of the present study was to investigate morphosyntactic processing in adults with Developmental Dyslexia, by means of an experimental task providing information about the behavioural skills through a grammaticality judgement task, and about the electrophysiological responses to agreement violations. Both at the behavioural and electrophysiological level, dyslexic participants showed differences with respect to controls, thus confirming the hypothesis of a syntactic processing ‘weakness’ in Developmental Dyslexia. At the electrophysiological level a classical bi-phasic pattern (LAN/P600) was expected for control participants, while anomalies were expected in the dyslexic group.

3.4.1 Interpretation of the ERP results

Partially in line with expectations, agreement violations evoked in the control group a broad positive wave (P600) between 450 and 850 ms. The absence of the Left Anterior Negativity, even in the control participants, is consistent with other studies that failed to find such an electrophysiological component with subject-verb agreement violations in various languages (Balconi & Pozzoli, 2005; Hagoort et al., 1993; Rispens et al., 2006; see Sections 2.2 and 2.3 for a further discussion).

In the dyslexic group a P600 also emerged, similarly to that found in the control group. However, statistical analyses showed subtle differences between the two groups concerning the latency of this electrophysiological component. The onset of the P600 was delayed of about 50 ms in the dyslexic group. Longer latencies for dyslexic children or adults have often been reported in previous studies, specifically concerning the P600 component (Rispens et al., 2006) or different electrophysiological components (Breznitz & Leikin, 2000; Helenius et al., 1999; Leikin, 2002; Sabisch et al., 2006; Torkildsen et al., 2007). These results have been generally interpreted as reflecting slower processing. Unfortunately, in the present study the electrophysiological delay cannot be corroborated by the behavioural data, because time reactions could not be recorded for the behavioural task due to the specific task procedure that required a delayed response.

No differences in the P600 amplitude emerged between groups, although it strongly correlated to reading skills in the dyslexic group. The analyses of correlations between electrophysiological and behavioural data showed an increase in the P600 amplitude in dyslexic participants with the more serious reading difficulties. As the increase in the P600 amplitude has often been associated with increase in syntactic integration difficulty (Kaan et al., 2000), it could be concluded that the dyslexics with more serious reading difficulties also displayed the more serious language processing difficulties.

A further intriguing outcome was the statistically significant early negativity in dyslexic participants. Because of its topography, this broadly diffused component peaking around 300 ms cannot be functionally interpreted as a LAN, reflecting the automatic detection of the morphosyntactic error (Coulson et al., 1998; Friederici, 2002). Rather, it resembles more an N400. Although the N400 is usually associated with semantic processing, N400-like components have been found to be associated with sentence processing and (morpho)syntactic violations in previous studies investigating special populations, such as children with a diagnosis of language impairment (Fontaneau & Van der Lely, 2008), aphasic patients (Hagoort, Wassenaar, & Brown, 2003), as well as adults learning a second language (L2) (Chen, Shu, Liu, Zhao, & Li, 2007; Osterhout et al., 2008;

K. Weber & Lavric, 2008) or an artificial language (Morgan-Short, Sanz, Steinhauer, & Ullman, 2010). In some of these studies, the finding of an N400-like component instead of the bi-phasic LAN-P600 pattern is interpreted as a partial compensation of the not completely developed (morpho)syntactic skills by means of a neural circuitry associated with semantic processing. This interpretation is supported by the wide literature on the semantic role of the N400 component, usually associated with the degree of lexical-semantic predictability at the sentence level and, more generally, with lexical-semantic integration (Kutas & Hillyard, 1980b).

More refined interpretations could be provided, particularly when considering recent evidence from L2 learners. The literature in the last years has focused on second language acquisition differentiating between stages of proficiency, ranging from very low to very high (native-like) proficiency (for a review see Steinhauer, White, & Drury, 2009). At the lowest stages, electrophysiological results show N400s in response to (morpho)syntactic violations (Morgan-Short et al., 2010; Osterhout et al., 2008), often in addition to a small or delayed P600 (Osterhout et al., 2008; Steinhauer, White, Cornell, Genesee, & White, 2006). Several cognitive processes have been assumed to contribute to these N400-like effects. In particular, it has been proposed that they reflect the low probability of the critical word in that position or a whole-form storage of morphologically complex forms.

This last explanation can be comprised in the *Declarative / Procedural (DP) model* proposed by Ullman (2001). According to this model, the linguistic representation and processing of the own's native language is based on two neurocognitive mechanisms: a declarative memory system consisting of a lexical store of memorised words rooted in temporal lobe structures, and a procedural memory system involved in processing combinatorial rules and rooted in frontal brain structures. When exposed to an implicit training, beginning L2 learners rely more on the declarative memory system (reflected in the N400s), as the procedural system is initially not accessible (Ullman, 2005), see also Clahsen and Felser (2006) for similar ideas. The distinction proposed by Ullman (2001) is particularly relevant within the morphological domain, where regular forms are produced by combination of rules (procedural memory system), while irregular forms are stored as full-forms (declarative memory system). In support of this distinction, ERPs studies on adults found LAN/P600 in response to regularisations (misapplication of rules to irregular verbs), and N400 in response to irregularisations (misapplications of irregular inflections) (Luck, Hahne, & Clahsen, 2006).

Extending this hypothesis to our study, it could be hypothesised that the dyslexic adults have difficulties in constructing implicit rules for handling inflectional morphology, and thus rely more on storage or ground on aspects of lexical-semantic predictability, resulting in the N400

enhancement. Similar hypotheses have been proposed for explaining grammatical difficulties in children with SLI (Gopnik et al., 1997; van der Lely, 2005b). According to these hypotheses, SLI children cannot understand the internal structure of inflected words, and thus preferentially use the lexical storage-associative system. For this reason, they do not show the normal regularity advantage, perform similarly on regular and irregular past-tense marking and manifest similar frequency effects for regular and irregular verbs (Ullman & Gopnik, 1999; van der Lely & Ullman, 2001).

Alternatively, it could be hypothesised that in order to overcome the difficulties in constructing implicit rules for handling inflectional morphology, explicit agreement rules should be learnt. Again, hypotheses from the study of L2 learning can provide an explanation. In particular, within the framework of ‘Universal Grammar’ (Chomsky, 1965), according to the ‘fundamental difference hypothesis’ (Bley-Vroman, 1989; DeKeyser, 2000), young children acquire their L1 implicitly with UG mechanisms, whereas late language learners depend largely on explicit, domain general cognitive functions. It could be hypothesised that, in order to process agreement violations, the dyslexic participants in the present study also need to retrieve the explicit rule, and this process could lead up to enhanced latency and to additional negativity.

3.4.2 Number manipulation

A further finding of the present study concerns the way singular and plural forms are processed. Similarly to Rispens et al.’s results (2006), in the present study statistically significant effects emerged from the number manipulation. Dyslexic participants seem to have more difficulties when processing plural sentences, as shown by the enhanced amplitude of the N400-like component, and by a broad positivity in response to the plural grammatical sentences, partially obscuring the P600 in response to the ungrammatical counterparts.

A possible explanation for these findings involves the complexity of the plural forms with respect to the singular ones: plural NPs are less frequent and more marked forms and put more burden on sentence processing mechanisms than singular NPs (Kaan et al., 2000).

These further cognitive demands might have stronger effects in dyslexic participants than in controls. The greater complexity of plural forms with respect to singular ones is widely supported by the literature on language acquisition. Plural morphemes are usually reported to be acquired later than singular ones in various languages, Italian included (Guasti, 2002), and they appear in the speech of Italian speaking children at more advanced level of linguistic development as measured by length of utterance (MLU) (Bortolini et al., 1997; Caprin & Guasti, 2009). This last study

showed that plural morphemes start to be employed by children with MLU in words ranging between 1.5 and 2, and increase in children with MLU between 2.0 and 3.1. Additionally, at least in the first phases of verbal agreement acquisition, a common error is the use of the third singular morpheme in the place of the third plural morpheme (Bortolini et al., 1997; Caprin & Guasti, 2009; Pizzuto & Caselli, 1992). As Bortolini and colleagues argued, these findings are compatible with a prosodic account, mainly related to difficulties with the production and comprehension of weak syllables outside a Strong-Weak (SW) sequence.

The singular/plural asymmetry is moreover supported by studies on the phenomenon of ‘agreement attraction’, observed when a noun, situated in the vicinity of the subject-verb agreement relation, imposes its number on the verb. It has often been found a significantly stronger attraction generated by plural intervening elements than by singular ones (Bock & Eberhard, 1993; Franck, Lassi, Frauenfelder, & Rizzi, 2006; Garraffa, 2009). Although these effects are explained in terms of markedness of plural nouns, the nature of this markedness is still unclear. Some approaches discuss markedness referring to a formalism about linguistic oppositions which assumes syntactic features to be binary and expressed by a marked value possessing a distinctive property [+ number] and by an unmarked one [- number] lacking that property (Jakobson, 1957). Other approaches, however, consider markedness just in terms of rarity or unexpectedness (Haspelmath, 2006), or in terms of ‘overt coding’, expressed by overt inflections (Diessel, 2007). Italian plural forms seem to point in this direction, as they are often less frequent and expressed by an additional syllable (at least in the verbal inflections considered in the present study). The consistent difference in length between singular and plural verbal forms, compounded with differences in frequency, could be responsible for the described electrophysiological results, with a different impact on dyslexics’ and controls’ electrophysiological responses.

The difference found in the control participants, however, is still difficult to interpret, and in need of further investigation, particularly because to our knowledge, none of the ERP studies on agreement has ever analysed singular and plural sentences separately. Thus, further studies in this direction seem necessary in order to understand the differences between singular and plural processing in typical participants. In particular, a role of this feature could be hypothesised to partially explain the non-robustness of findings across studies, principally on what concerns the enhancement of negativities.

3.4.3 Conclusions and limits of the study

In conclusion, the present results support the hypothesis of different and anomalous language processing modalities in Developmental Dyslexia, thus confirming a general morphosyntactic processing ‘weakness’ in DD, that does not emerge from the test usually adopted to diagnose dyslexia. This result is particularly relevant within the open debate concerning the linguistic nature of DD and its overlap with SLI (e.g. Bishop & Snowling, 2004). The existence of an indefinite border between the two disorders is thus confirmed, given the fact that anomalies in the morphosyntactic domain, typically impaired in SLI children, have been found in participants with DD. This clearly suggests that language is impaired, at least to some extent, in DD participants, something that current theories of dyslexia cannot account for in a simple way.

Despite the robustness of our findings, it should be noted that our participants were adults (not-compensated) developmental dyslexics. Although the generalisability of the study may be intrinsically limited by the age of our participants (Ramus et al., 2003), our sample could be considered heterogeneous and representative of the general dyslexic population, with respect to both scholastic achievement (ranging from technical school to university) and sex (4 females and 12 males, in line with reported prevalence; Liederman, Kantrowitz, & Flannery, 2005). However, it is possible that our participants’ language skills have been improved with age, partially compensating their language deficit. Moreover, our investigation was limited to individuals with DD, and did not include a further group with additional SLI. To better understand the nature of the linguistic deficit, further investigations need to examine dyslexic participants with a concomitant language impairment, and participants at various stages of development. Such study will be the focus of the next Chapter.

Appendix 3A: Stimuli for the subject-verb agreement experiment

Experimental sentences

- 1 La bambina bruna gioca/giocano* a palla
- 2 La sirena bionda gioca/giocano* nel mare
- 3 Le papere paffute mangiano/mangia* con piacere
- 4 Le giraffe alte mangiano/mangia* nella savana
- 5 Il mago saggio vive/vivono* da solo
- 6 La foca grigia vive/vivono* al freddo
- 7 Le bimbe felici corrono/corre* nei prati
- 8 I ciclisti agili corrono/corre* in bicicletta
- 9 la zebra striata galoppa/galoppano* al tramonto
- 10 Il cavallo bianco galoppa/galoppano* nel campo
- 11 I pulcini buffi zampettano/zampetta* nel pollaio
- 12 Le galline grasse zampettano/zampetta* nel cortile
- 13 La balena grigia galleggia/galleggiano* nel mare
- 14 Il tronco spezzato galleggia/galleggiano* sull'acqua
- 15 I cani feroci morsicano/morsica* con violenza
- 16 I conigli fifoni morsicano/morsica* con facilità
- 17 La lumaca lenta striscia/strisciano* sul muro
- 18 La vipera svelta striscia/strisciano* tra i cespugli
- 19 I muri antichi crollano/crolla* all'improvviso
- 20 I templi romani crollano/crolla* per il terremoto
- 21 Il quadro prezioso cade/cadono* dalla parete
- 22 Il pastello nero cade/cadono* dal tavolo
- 23 Le maestre serie scrivono/scrive* alla lavagna
- 24 I poeti celebri scrivono/scrive* con impegno
- 25 la formica precisa lavora/lavorano* senza sosta
- 26 La commessa stanca lavora/lavorano* di sera
- 27 Le onde enormi arrivano/arriva* sulla spiaggia
- 28 Le atlete scattanti arrivano/arriva* al traguardo
- 29 il marito noioso legge/leggono* nel letto
- 30 La signora curiosa legge/leggono* sull'autobus
- 31 Le amiche contente ridono/ride* in spiaggia
- 32 I ragazzi felici ride/ridono* di gusto
- 33 Il cigno respinto muore/muoiono* per il dolore
- 34 La capra anziana muore/muoiono* di vecchiaia
- 35 I ragni pelosi salgono/sale* sull'albero
- 36 I marziani verdi salgono/sale* sull'astronave
- 37 La sorella riccia cerca/cercano* nei cassetti
- 38 Il turista straniero cerca/cercano* sulla cartina
- 39 I ghiri sfiniti entrano/entra* in letargo
- 40 I serpenti viscidati entrano/entra* nelle tane

- 42 Il traghetto rapido parte/partono* dal porto
- 41 La famiglia unita parte/partono* per le vacanze
- 43 I bicchieri puliti servono/serve* per bere
- 44 Le formule segrete servono/serve* per una magia
- 45 Il bimbo sereno dipinge/dipingono* con le tempere
- 46 La pittrice carina dipinge/dipingono* sul balcone
- 48 I parenti curiosi rispondono/risponde* al telefono
- 47 I malati nervosi rispondono/risponde* all'infermiera
- 49 La strega cattiva vola/volano* sulla scopa
- 50 La farfalla rossa vola/volano* sui fiori
- 51 Le lepri agili scappano/scappa* nel cortile
- 52 I topi veloci scappano/scappa* nella tana
- 53 Il pollo arrosto gira/girano* sullo spiedo
- 54 Il pianeta tondo gira/girano* nello spazio
- 55 Le rane verdi saltano/salta* nello stagno
- 56 I delfini svegli saltano/salta* sulle onde
- 57 Il gambero rosso cammina/camminano* all'indietro
- 58 La donna sportiva cammina/camminano* in montagna
- 59 I concerti lunghi iniziano/inizia* alle otto
- 60 Le vacanze estive iniziano/inizia* a giugno
- 61 La campana dorata suona/suonano* a festa
- 62 Il violino magico suona/suonano* da solo
- 63 I galli testardi cantano/canta* all'alba
- 64 Le cantanti famose cantano/canta* sul palco
- 65 Il negozio piccolo chiude/chiudono* alle cinque
- 66 La mensa diurna chiude/chiudono* alle quattordici
- 67 I fiori gialli crescono/cresce* nei prati
- 68 I frutti succosi crescono/cresce sulle piante
- 69 La gazza ladra ruba/rubano* nel vigneto
- 70 Il ladro esperto ruba/rubano* nelle case
- 71 Le idee geniali durano/dura* nel tempo
- 72 Le guerre lunghe durano/dura* degli anni
- 73 Il cucciolo giocoso disturba/disturbano nella notte
- 74 Il compagno sbadato disturba/disturbano* in classe
- 75 I cammelli robusti avanzano/avanza* nel deserto
- 76 Le armate nemiche avanzano/avanza* sulla città
- 78 La zia graziosa cura/curano* con amore
- 77 Il medico dotto cura/curano* in ospedale
- 79 Le suore devote pregano/prega* in ginocchio
- 80 I frati pelati pregano/prega* in chiesa
- 81 Il vento gelido soffia/soffiano* dalle montagne
- 82 Il babbo festoso soffia/soffiano* sulle candeline
- 83 Le stelle splendenti brillano/brilla* di notte
- 84 Le pietre preziose brillano/brilla* sulla corona

- 86 Il drago malvagio appare/appaiono* dietro al castello
85 La nuvola scura appare/appaiono* all'improvviso
87 I fantasmi bianchi compaiono/compare* di notte
88 Le lucciole dorate compaiono/compare* al tramonto
89 Il micio vispo sporca/sporcano* in salotto
90 Il criceto peloso sporca/sporcano* in casa
91 Le talpe cieche scavano/scava* nella terra
92 Le ruspe pesanti scavano/scava* nella cava
93 Il cervo svelto saltella/saltellano* sui sentieri
94 Il grillo leggero saltella/saltellano* sulle ninfee
95 I maiali sporchi rotolano/rotola* nel fango
96 Le palle azzurre rotolano/rotola* per terra
97 La nonna anziana riposa/riposano* sul divano
98 Il canguro vecchio riposa/riposano* sul prato
99 Le giostre nuove funzionano/funziona* a motore
100 I giochi moderni funzionano/funziona* a pile
101 La tenda solida ripara/riparano* dal vento
102 La grotta spaziosa ripara/riparano* dalla pioggia
103 Le cuoche golose cucinano/cucina* con piacere
104 Le mogli attente cucinano/cucina* con amore
105 Il maestro severo urla/urlano* in classe
106 La scimmia allegra urlano/urla* nella giungla
107 Le ragazze sportive nuotano/nuota* in piscina
108 I pesci tranquilli nuotano/nuota* nell'acquario
109 La fata turchina sorride/sorridono* con grazia
110 Il pagliaccio buffo sorride/sorridono* ai bambini
111 I soldati armati combattono/combatte* con coraggio
112 I pugili sudati combattono/combatte* in palestra
113 La finestra rotta sbatte/sbattono* al vento
114 Il picchio distratto sbatte/sbattono* contro il vetro
115 Le salsicce fresche cuociono/cuoce* sulla griglia
116 Le ciambelle bucate cuociono/cuoce* nel forno
117 Il legno secco brucia/bruciano* nel camino
118 La casa vuota brucia/bruciano* nell'incendio
119 Le navi veloci viaggiano/viaggia* nell'oceano
120 I treni lenti viaggia/viaggiano* per la campagna
121 Il sentiero ripido termina/terminano* nel bosco
122 La cascata limpida terminano/termina* nella valle
123 Le regine amate comandano/comandano* dai troni
124 I principi furbi comandano/comanda* con astuzia
125 Il pirata spietato naviga/navigano* nell'oceano
126 Il veliero greco naviga/navigano* nel mare
127 I razzi spaziali atterrano/atterra* sulla luna
128 I dischi volanti atterrano/atterra* sulla città

- 129 Il passero tranquillo cinguetta/cinguetta* tutto il giorno
- 130 La colomba quieta cinguetta/cinguettano* sul ramo
- 131 I nonni allegri educano/educa* con saggezza
- 132 Le madri severe educano/educa* con rigore
- 133 La barista carina balla/ballano* sui tavoli
- 134 La dama ingenua balla/ballano* col principe
- 135 Le fanciulle ingenue sognano/sogna* sul prato
- 136 Le fatine dolci sognano/sogna* ad occhi aperti
- 137 La mosca nera ronza/ronzano* in camera
- 138 La zanzara noiosa ronza/ronzano* in cucina
- 139 I rifiuti vecchi puzzano/puzza* per le strade
- 140 I cinghiali pelosi puzzano/puzza* di sporczia
- 141 La pozione magica bolle/bollono* nel pentolone
- 142 Il risotto giallo bolle/bollono* sul fornello
- 144 Le persone bugiarde mentono/mente* con astuzia
- 143 Le figlie monelle mentono/mente* ai genitori
- 145 La folla festosa ringrazia/ringraziano* con gli applausi
- 146 Il cugino contento ringrazia/ringraziano* del regalo
- 147 Le stufe accese riscaldano/riscalda* in inverno
- 148 I camini caldi riscaldano/riscalda* con la legna
- 149 Il letto scassato scricchiola/scricchiolano* di continuo
- 150 La porta rotta scricchiola/scricchiolano* ogni giorno
- 151 Le cicogne piumate migrano/emigra* in inverno
- 152 Le anatre selvagge migrano/emigra* verso il caldo
- 153 Il tacchino grasso sbuca/sbucano* dal pollaio
- 154 Il lupo cattivo sbuca/sbucano* dal bosco
- 155 I gatti furiosi graffiano/graffia* con rabbia
- 156 Le tigri feroci graffiano/graffia* con gli artigli
- 157 La bomba violenta esplode/esplodono* in città
- 158 Il petardo chiassoso esplode/esplodono* per la strada
- 159 I furfanti furbi evadono/evade* dal carcere
- 160 I briganti violenti evadono/evade* dalla prigione
- 161 la sposa stanca dorme/dormono* sul divano
- 162 La gazzella sfinita dorme/dormono* nella savana
- 163 I leoni decisi escono/esce* allo scoperto
- 164 Le volpi scattanti escono/esce* dalle tane
- 165 La stella cometa ritorna/ritornano* ogni anno
- 166 Il bambino serio ritorna/ritornano* da scuola
- 167 I signori distinti aspettano/aspetta* alla fermata
- 168 Le pazienti ansiose aspettano/aspetta* nell'atrio

Filler sentences

- 1 Francesca è caduta/ha caduto* dalla sedia
- 2 L'aereo è precipitato/ha precipitato* sulle montagne
- 3 La nave è affondata/ ha affondato* nel mare
- 4 L'elicottero è decollato/ ha decollato* dalla piattaforma
- 5 Giulia è scesa/ ha sceso* in cantina
- 6 Il sole è tramontato/ha tramontato* dietro alle montagne
- 7 Maurizio è guarito/ha guarito* in pochi giorni
- 8 La guerra è scoppiata/ha scoppiato* senza motivo
- 9 Le rose sono sbocciate/hanno sbocciato* in anticipo
- 10 Gli operai sono andati/hanno andato* a mangiare
- 11 Le alunne sono arrivati/hanno arrivato* in ritardo
- 12 I figli sono rimasti/hanno rimasto* a casa
- 13 I micetti sono nati/hanno nato* di notte
- 14 Le attrici sono uscite/hanno uscito* dai camerini
- 15 I capelli sono cresciuti/hanno cresciuto* di 10 cm
- 16 Le automobili sono scivolato/hanno scivolato* sul ghiaccio
- 17 Monica ha bussato/è bussato* alla porta
- 18 Luca ha litigato/è litigato* con la mamma
- 19 Luisa ha pianto/è pianto* per la nostalgia
- 20 Luigi ha sbadigliato/è sbadigliato* per la noia
- 21 Michela ha telefonato/è telefonato* al fidanzato
- 22 Valentina ha parlato/è parlato* con la maestra
- 23 Federico ha pranzato/è pranzato* da solo
- 24 L'arbitro ha fischiato/è fischiato con decisione
- 25 I soldati hanno marciato/sono marciati* per la città
- 26 Le poliziotte hanno sparato/sono sparati* al ladro
- 27 I genitori hanno cenato/sono cenati* al ristorante
- 28 Le campionesse hanno partecipato/sono partecipati* alla gara
- 29 Gli innamorati hanno passeggiato/sono passeggiati sul lungo mare
- 30 Gli zii hanno viaggiato/sono viaggiati per il mondo
- 31 I leoni hanno ruggito/sono ruggiti* per spaventare le prede
- 32 Le bambine hanno tremato/sono tremate* dalla paura

Chapter 4

Study 2:

Phonological and morphosyntactic processing in Italian dyslexic children with and without specific language impairment

4.1 Experimental questions and outline of the chapter

The main aim of the present study was to compare the neuropsychological profiles of subgroups of Italian dyslexic children characterised by the presence (DD+SLI) or absence (DD-Only) of Specific Language Impairment. For this purpose, a comprehensive evaluation of verbal abilities was carried out using both behavioural and electrophysiological measures of phonological and morphosyntactic processing. The interest in this investigation has been sparked by both theoretical and clinical issues.

When reviewing the general characteristics of DD and SLI, we have seen that the two disorders share common cognitive deficits, mainly in the linguistic sphere. Both DD and SLI children suffer from phonological deficits (e.g., Gathercole & Baddeley, 1990a; Snowling, 2000). In addition, while (morpho)syntactic deficits are considered the core impairment in SLI (Clahsen, 1989; Gopnik et al., 1997; Rice et al., 1995; van der Lely, 2005a), there is some evidence of impairment in this domain in DD individuals as well (see Section 1.2.2 for an extensive review). Given these common symptoms, the nature of the overlap between DD and SLI is a theoretical issue that has received considerable attention. As reviewed in Section 1.3.2, different hypotheses have been proposed in order to clarify the relationship between the disorders: **1) Severity model** (Tallal et al., 1997): DD and SLI are consequences of the same underlying cognitive disorder and only differ in the degree of the severity **2) Bidimensional model** (Bishop & Snowling, 2004): both DD and SLI derive from a

phonological deficit of similar severity, while SLI children are additionally impaired in other non-phonological linguistic domains **3). Comorbidity model** (Catts et al., 2005): DD and SLI are distinct disorders and the overlap is due to comorbidity. However, the experimental evidence does not completely support any of these models. Recently, a fourth model has been proposed by Pennington and Bishop (2009), named **Multiple overlapping risk factor model**, suggesting that developmental disorders derive from multiple underlying deficits and comorbidity results from some of these underlying deficits being shared by different disorders. The evaluation of the neurophysiological profiles of DD children with and without SLI might help in clarifying the relationship between the two disorders. To our knowledge, this is the first attempt to characterise the profiles of the subgroups concerning different domains of linguistic processing (phonology and morphosyntax) using both behavioural and electrophysiological measures. Specifically, two sets of questions are addressed:

- a) *Assuming that both DD-Only and DD+SLI children are characterised by phonological impairments, the question remains, are these deficits the same or different? And if the behaviours do differ, are the differences quantitative or qualitative?*

The presence of qualitatively different phonological deficits in the two populations would allow us to exclude the possibility that the same impairment underlies DD and SLI, thus confirming the presence of a constellation of different cognitive deficits, whose associations lead to the emergence of different behavioural profiles.

- b) *When using particularly sensitive measures, is it possible to determine whether DD is associated with a broader linguistic impairment, particularly concerning the morphosyntactic domain? Again, is the morphosyntactic impairment similar to that shown by DD+SLI children (only less severe) or are there qualitative differences between groups?*

This question has already been partially answered by the results of the study on Italian dyslexic adults (Chapter 3). DD adults seem to process morphosyntactic violations differently from controls, thus reflecting a general linguistic weakness and the use of qualitatively different cognitive strategies. The present study allows us to add information about the developmental trend of the cognitive strategy used by DD individuals, and to compare the performance with children that have a formal deficit in language processing. Again, the presence of qualitatively different deficits in the two populations would allow us

to exclude the possibility that the same impairment underlies DD and SLI, thus confirming the presence of different cognitive deficits whose associations lead to the emergence of different behavioural profiles.

In addition, the possible presence of subtle linguistic deficits in DD children without any formal diagnosis of SLI opens the question of the appropriateness of clinical instruments for the assessment of linguistic skills in school-aged children. It could be that the linguistic deficits in these children have been underestimated due to the weak sensitivity of linguistic tests used for the formal assessment in the clinical practice. For this reason, different tests were used to tap syntactic and morphosyntactic skills. These measures were characterised by different degrees of sensitivity with the use of Event-Related Potentials (ERPs) situated at the end of the continuum, representing one of the most sensitive measures to investigate linguistic processing. We are aware that ERPs cannot provide a solution to the lack of sensitive tests in the clinical practice, but they could help in detecting the “clinical markers”, in order to create behavioural tests sensitive enough to pick up on subtle morphosyntactic deficits in the dyslexic population. A third question, with a more clinical goal, is addressed:

c) In light of the results in the formal and experimental linguistic evaluation in DD only children, do we need new diagnostic tests able to detect more subtle linguistic difficulties in school-aged children?

After a general methodological section, in which the characteristics of the sample are described, the chapter is divided into three sections. **Experiment 1** presents the behavioural results concerning phonological variables (i.e., short-term memory, non-word repetition, phonological awareness). **Experiment 2** presents the behavioural results concerning non-phonological linguistic variables (i.e., semantic comprehension, syntactic comprehension, production of inflectional morphology and sensitivity to violations through a grammaticality judgement task). **Experiment 3** presents the electrophysiological correlates of subject-verb agreement violations. After each section a discussion of the data is provided. In addition, a general discussion is presented in Section 4.6, in attempt to answer to experimental questions mentioned above.

4.2 General method

4.2.1 Participants

Forty-eight children aged between 8 and 13 years participated in the study: 16 normal-reading control children, 16 dyslexic children without any history of language impairment, and 16 dyslexic children with an additional diagnosis of SLI. The participants in the three groups were individually matched for gender and age. Parental consent was obtained after the purpose and procedures of the study had been explained. The study had been approved by the Ethics Committee of the Institute “E. Medea”, according to standards of the Helsinki Declaration (1964).

Dyslexic children included in the sample had been referred to the Unit of Cognitive Psychology and Neuropsychology of the Scientific Institute “E. Medea” because of learning difficulties. All children had been diagnosed as dyslexic based on standard inclusion and exclusion criteria (ICD-10; World Health Organization, 1992). Their performance in reading was two (or more) standard deviations below the mean in at least one of the age-standardised Italian reading tests included in the battery (word, non-word and text reading), and their non-verbal or performance IQ was above 85. Performance IQ was estimated by Cattell’s “Culture Free” test (Cattell, 1979). Within the dyslexic children, two subgroups based on the presence or absence of a concomitant language impairment were created. The selection of the participants in the two subgroups was based on an accurate analysis of clinical reports. In particular, previous diagnoses and anamneses as reported by parents were considered, including reports of significant and persistent delays in early vocabulary and syntactic development, and possibly, history of speech and language therapy. Additionally, standardised language tests were performed, in order to assess the current linguistic performance. In addition to a previous diagnose of language impairment, all children in the **DD+SLI** group had performances in linguistic skills still significantly below the mean in at least one of the age-standardised Italian tests included in the battery. In order to be included in the DD+SLI group, children should have a performance one and half (or more) standard deviations below the mean in the standardised test for syntactic comprehension (TCGB, Chilosi & Cipriani, 1995) or they should have a performance two (or more) standard deviations below the mean in at least two subtests of an internal-use standardised battery for morphological and morphosyntactic skills (Co.Si.Mo., Milani et al., 2005). On the other hand, children in the **DD-only** group had no concomitant diagnose of language impairment, and no linguistic delay reported by parents. Additionally, all children in the DD-only group performed normally in the linguistic tasks included in the battery.

Control children were recruited in local schools. They all performed normally in the reading and linguistic tasks included in the battery, and their performance IQ (Cattell’s “Culture Free” test) was above 85.

Participant characteristics compared with a one-way ANOVA are shown in Table 4.1. Children’s age did not differ statistically. Reflecting the recruitment criteria, both dyslexic groups differ significantly from the control group in all reading scores. Interestingly, the two dyslexic groups do not differ from each other in any reading measures, suggesting that the reading deficit was similar in the two groups. Additionally, group differences emerged between the DD+SLI group and both the control group and the DD-only group in the syntactic comprehension task. Although differences concerning performance IQ emerged between the DD+SLI and the control group, the IQ scores were relatively high for both groups (as shown by the mean scores). Given the absence of correlations between performance IQ and phonological and linguistic measures in the separate groups, no covariate for IQ was entered in the analyses.

VARIABLES	CONTR Mean (SD)	DD-ONLY Mean (SD)	DD+SLI Mean (SD)	One-way ANOVA (<i>p</i>-value)
N (Female)	16 (7)	16 (7)	16 (7)	
Age in months	123.0 (17.18)	121.1 (13.63)	119.3 (14.93)	.794
Performance IQ	117.4 (10.51)	111.1 (10.66)	105.8 ^a (9.20)	.009
Text reading: accuracy	0.21 (0.50)	-2.48 ^a (0.86)	-1.98 ^a (1.69)	<.001
Text reading: speed	0.30 (0.35)	-1.53 ^a (1.37)	-1.35 ^a (1.12)	<.001
Word reading: accuracy	0.45 (0.43)	-2.13 ^a (1.18)	-2.74 ^a (2.59)	<.001
Word reading: speed	0.58 (0.63)	-3.21 ^a (2.64)	-2.53 ^a (2.59)	<.001
Non-word reading: accuracy	0.24 (0.73)	-1.85 ^a (1.25)	-2.30 ^a (2.07)	<.001
Non-word reading: speed	0.19 (0.67)	-1.87 ^a (1.49)	-1.55 ^a (1.60)	<.001
Syntactic comprehension	0.24 (0.73)	0.18 (0.63)	-1.59 ^{a,b} (1.54)	<.001
Semantic comprehension	0.69 (0.81)	0.78 (0.72)	0.04 (1.00)	.068

^a Score significantly lower than control group on Tukey-HSD post-hoc tests set at $p < .005$

^b Score significantly lower than DD-only group on Tukey-HSD post-hoc tests set at $p < .005$

Table 4.1. Participants characteristics

4.2.2 Tests of reading skills

Reading skills were assessed through two different tasks:

- Text reading: “Prove di lettura MT per la scuola elementare-2” (Reading tests for primary school, Cornoldi, Colpo, & Gruppo, 1998) and “Nuove prove di lettura MT per la scuola media

inferiore” (New Reading tests for secondary school, Cornoldi & Colpo, 1995) widely used Italian tests providing accuracy and speed scores in reading age-normed texts aloud.

Word and non-word reading. “Batteria per la valutazione della dislessia e disortografia evolutiva” (Battery for the assessment of Developmental Reading and Spelling Disorders, Sartori et al., 1995). In particular, speed and accuracy z-scores were computed for single word (4 lists of 28 words) and non-word reading (3 lists of 16 non-words).

4.2.3 General testing procedure

Standardised tests and experimental tasks were both conducted individually in laboratories of the scientific institute. The experimental task lasted approximately 45 minutes, and additionally 30-45 minutes were necessary to prepare the participant for the EEG recording. The standardised tests were generally performed in a second session, approx. two weeks after the first session. Control participants were administered the whole battery by the experimenter, while for some of the dyslexic children the tests were administered by a clinical psychologist or a speech-therapist during clinical assessment.

4.3 Experiment 1: Behavioural characterisation in phonological skills

4.3.1 Assessment

4.3.1.1 Tests of verbal short-term memory and phonological processing

Verbal short-term memory was assessed using three different tasks. While the first task (digit span) specifically involves short-term memory (digit span forward) as well as working memory (digit span backward), the second and third tasks additionally involve phonological processing skills.

- Digit span: The “forward” and “backward” digit span tasks of an Italian standardised battery were used (“Batteria di Valutazione Neuropsicologia per l’età evolutiva”; battery for the neuropsychological evaluation in developmental age, Bisiacchi, Cendron, Tressoldi, Vio, & Gugliotta, 2005). Children were presented auditorily with series of numbers (forward, from 3 to 9 digits in a row; backward, from 2 to 8 digits in a row) and were asked to repeat them (in the backward condition children were asked to repeat them in reversed order). Three separate series were proposed for each list length, and testing was discontinued when the child failed to repeat all

three series of the same length. Separate scores were computed for forward and backward digit span, consisting in the two higher span scores (with at least two series correctly produced). Referring to the norms, separate z-scores were also computed.

- Monosyllabic non-word span: A subtest of an internal-use standardised battery to assess phonological awareness was used (already described in Section 3.2.2.2., Rigamonti, Cantiani, Marino, & Lorusso, 2009). Participants were auditorily presented with series of monosyllabic non-words (for example ‘caf – nab’) increasing in number (from 2 to 8 monosyllabic non-words in a row), and were asked to repeat them back. Each list length consisted of two separate items, and testing was discontinued when the child failed to repeat both items of the same category. The higher span score was recorded.

- Non-word repetition: A subtest of an Italian standardised battery was used (“Batterie per la valutazione dell’attenzione uditiva e della memoria di lavoro fonologica nell’età evolutiva”; Batteries for the evaluation of auditory attention and phonological working memory in developmental age, Bertelli & Bilancia, 2006). The test includes 40 nonsense words, ranging in length from two to five syllables (10 items for each syllable length). Phonological complexity is manipulated through the presence or absence of consonant clusters CCV and CCCV. All non-words are conformed to the phonotactic constraints of Italian. The items were played to the participants on a laptop computer through loudspeakers. The accuracy score was computed as the number of correctly repeated non-words (maximum 40). Additionally, separate accuracy scores for each non-word length were computed, as well as error scores for phonological complex syllables (containing consonant clusters, CCV and CCCV).

4.3.1.2 Tests of phonological awareness

Phonological awareness was assessed with four tasks taken from an internal-use standardised battery (Rigamonti et al., 2009), with normative data for adults only (an adapted-to-children version of the battery is described in Section 3.2.2). In all the tasks the experimenter provided an auditory presentation of non-words, and different types of explicit manipulations were requested (oral answers required):

- Syllabic segmentation: Children were asked to syllabify auditorily presented non words (for example: ‘custone’ should become ‘cu-sto-ne’).

- Syllabic manipulation: Children were asked to displace the last syllable of a non-word to the beginning of the same non-word. The same non-words used in the syllabic segmentation task were used (for example: ‘cu-sto-ne’ should become ‘ne-cu-sto’).

- Spoonerisms: Children were asked to swap the initial phonemes of two one-syllable auditorily presented non-words (for example: ‘des’ and ‘mag’ should become ‘mes’ and ‘dag’).
- Phoneme synthesis: Children were asked to integrate auditorily presented phonemes sequentially into non-words (for example: l-e-m should become ‘lem’).

For each task 10 items were presented, with the first one used as familiarisation trial, and the following 9 items used as experimental items. Raw scores were computed for accuracy (number of correct items over 9). For the ‘Spoonerism’ task, the accuracy score was computed with respect to each phoneme replacement (maximum score 18). For the ‘Phoneme synthesis’ task, an additional score was computed as the number of correctly pronounced phonemes (maximum score 69).

4.3.2 Results

4.3.2.1 Verbal short-term memory: Digit and monosyllabic non-word span

The memory span scores for digit (forward and backward) and monosyllabic non-words are displayed in Figure 4.1. One-way ANOVAs were performed to estimate the differences between groups in the three tasks. The analyses showed significant group differences in all the three tasks (Digit span repeated forward, $F(2,46) = 3.47$; $p < .05$; Digit span repeated backward, $F(2,46) = 6.65$; $p < .005$; Monosyllabic non-words, $F(2,47) = 5.808$; $p < .01$)¹⁴. Post-hoc analyses (Tukey-HSD test) showed that only the comparison between control children and children in the DD+SLI group reached statistical significance (all $p_s < .05$), while the difference between control children and children in the DD-only group approached significance only in the Digit span backward task ($p = .061$), where working memory is additionally involved, and in the Monosyllabic non-word span ($p = .089$), where phonological processing is additionally involved. Again, no differences were found between the two dyslexic groups (all $p_s > .05$). These results suggest that DD+SLI children are impaired with respect to control children in all the tasks. In contrast, DD-Only children are moderately impaired with respect to control children only in those tasks simultaneously involving different skills (i.e., STM and WM, or STM and phonological processing) (See analyses on individual scores in Appendix 4A).

¹⁴ However, when applying the Bonferroni correction for multiple testing (setting α at 0.016) the difference in the forward digit span is no longer statistically significant ($p = 0.04$).

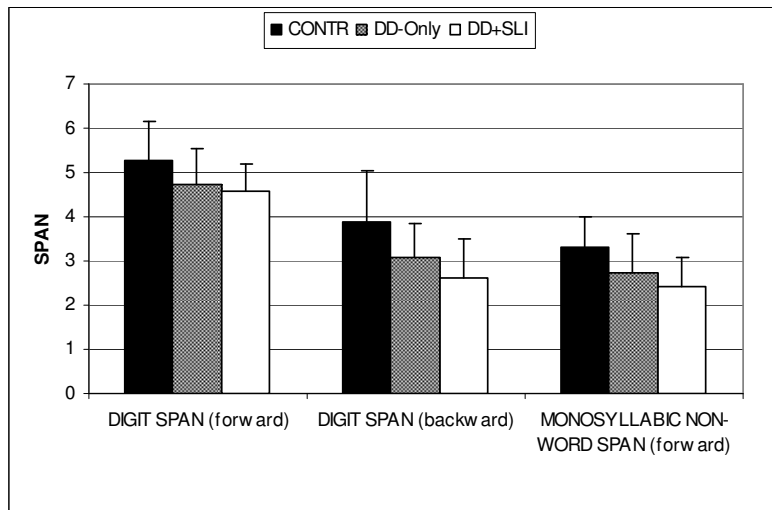


Figure 4.1: Memory Span scores

4.3.2.2 Non-word repetition

The raw scores for accuracy in the Non-word repetition task are displayed in Figure 4.2. A one-way ANOVA with Group as between-subject factor revealed significant group differences, $F(2,46) = 12.77$; $p < .001$. Post-hoc analyses (Tukey-HSD test) showed significant differences between Control children and both DD-Only children ($p = .02$) and DD+SLI children ($p < .001$), and an additional difference approaching statistical significance was found between the two groups of dyslexic children ($p = .07$) (See analyses on individual scores in Appendix 4A).

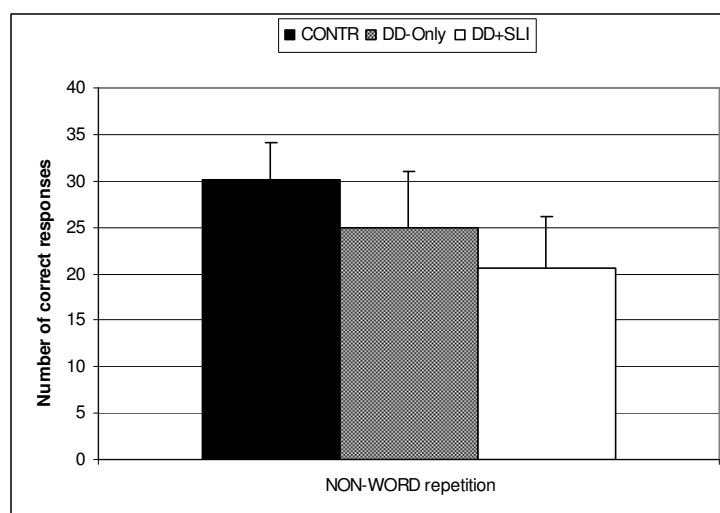


Figure 4.2: Accuracy scores on the Non-word repetition task (maximum score = 40).

Further analyses were performed taking into account differences concerning non-word length in

syllables¹⁵. Figure 4.3 displays the number of errors for the three groups, clearly showing that non-word difficulty increases as a function of non-word length. A repeated measure ANOVA was conducted on the number of errors, with Group as between-subject factor and Length as within-subject factor. In addition to the already reported main effect of Group, a significant main effect of Length emerged, $F(3,132) = 65.13$; $p < .001$, confirmed the increasing difficulty of non-words as a function of length (number of errors in the two-syllable condition, $M = 2.32$; $SD = 1.00$; three-syllable condition, $M = 2.94$; $SD = 1.92$; four-syllable condition, $M = 3.62$; $SD = 12.46$; five-syllable condition, $M = 6.02$; $SD = 2.46$; all contrasts $< .05$). In addition, the interaction Length * Group was also significant $F(2,44) = 11.33$; $p < .001$.

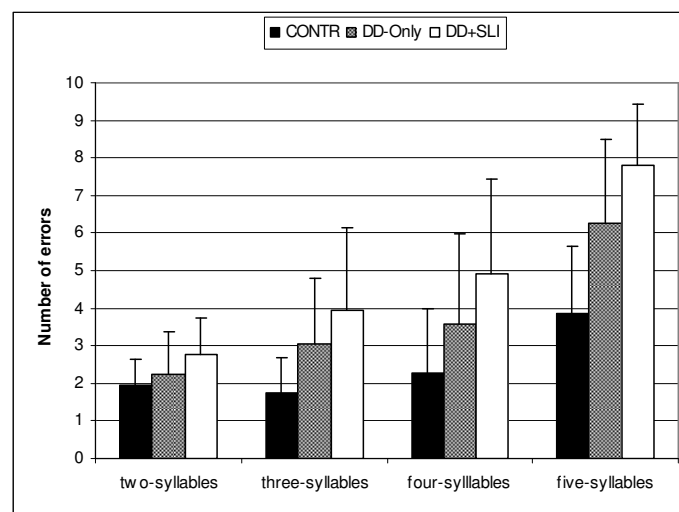


Figure 4.3: Errors in the Non-word repetition task. Scores are divided according to non-word length in syllables (maximum error score = 10)

One-way ANOVAs for errors in the different length conditions revealed that differences between groups increased as a function of non-word length (two syllables, $F(2,46) = 2.84$; $p = .069$; three syllables, $F(2,46) = 6.39$; $p < .005$; four syllables, $F(2,46) = 5.44$; $p < .01$; five syllables, $F(2,46) = 17.05$; $p < .001$)¹⁶. The results of the post-hoc analyses (Tukey-HSD test) are shown in Table 4.2. Although the differences between the control and the DD+SLI groups were almost always significant, the differences between the control and the DD-Only groups were significant only in the five-syllable condition. In addition, the difference between the two dyslexic groups also approached statistical significance in this last condition. Given these results, a specific impairment in short-term memory can be hypothesised in DD-Only children, while DD+SLI children seem to be characterised by a phonological processing deficit, in addition to the short-term memory ones.

¹⁵ Non-words of different lengths were perfectly balanced according to presence/absence of consonant clusters and phonotactic probability (measure of the likelihood of occurrence of a sound sequence). See Bertelli and Bilancia (2006) for further details.

¹⁶ When applying the Bonferroni correction for multiple testing (setting α at 0.0125) all comparisons are significant except for 2-syllables non-words.

COMPARISON	Two-syllables	Three-syllables	Four-syllables	Five-syllables
CONTR vs. DD-ONLY	.635	.092	.257	.003
CONTR vs. DD+SLI	.059	.003	.005	<.001
DD-ONLY vs. DD+SLI	.317	.332	.208	.061

Table 4.2. Differences between groups (expressed as p-values in the post-hoc analyses) concerning the errors in the Non-word repetition task

Finally, a third set of analysis was performed, in order to investigate the errors due to the phonological complexity of non-words (presence of two types of consonant clusters, namely CCV as in “*foblitego*” and CCCV as in “*sbralogamevi*”). For each participant, the number of errors involving syllables containing no or different types of consonant clusters was computed and transformed into percentage of errors. Given the absence of a significant difference between the overall percentage of errors in CCV and CCCV syllables ($t[46] = -1.58; p > .05$), a composite score was created. Figure 4.4 displays the percentage of errors in the three groups.

A repeated measure ANOVA was conducted on the percentage of errors, with Group as between-subject factor and Cluster (presence vs. absence) as within-subject factor. In addition to the expected main effect of Group, $F(2,44) = 12.65; p < .001$, and the main effect of Cluster, $F(1,44) = 141.95; p < .001$, an interesting significant interaction Cluster * Group emerged, $F(2,44) = 6.93; p < .005$. Due to this interaction, separate one-way ANOVAs were performed, revealing significant main effects of Group in both conditions (No cluster errors, $F(2,46) = 9.15; p < .001$; Cluster errors, $F(2,46) = 10.77; p = .001$). Interestingly, post-hoc analyses (Tukey-HSD test), reported in Table 4.3, revealed a different pattern in the two dyslexic groups.

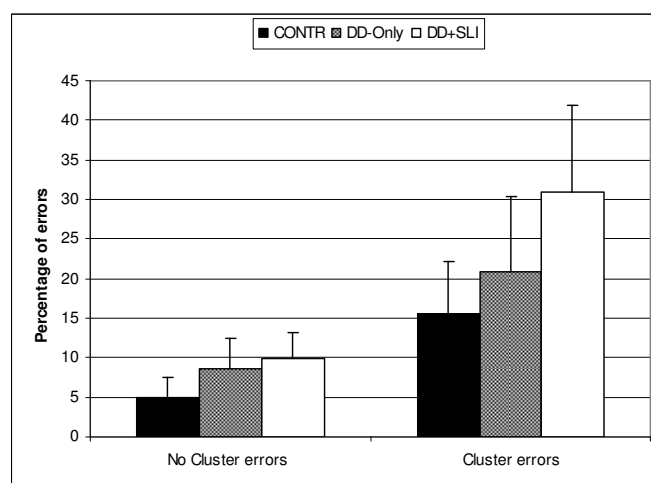


Figure 4.4: Percentage of errors in the Non-word repetition task.

Scores are divided according to presence or absence of consonant clusters.

Errors in the DD-Only group seem not to be related to phonological complexity. In fact, they did not show more errors than control children in syllables containing consonant clusters. Their difficulty can thus be interpreted as mainly reflecting deficits in short-term memory. In contrast, DD+SLI children's problems seem to be related to both short-term memory and phonological complexity, as their performance is significantly different from that of control children both in the presence and in the absence of consonant clusters.

COMPARISON	No cluster errors	Cluster errors
CONTR vs. DD-ONLY	< .005	.287
CONTR vs. DD+SLI	< .001	< .001
DD-ONLY vs. DD+SLI	.329	< .01

Table 4.3. Differences between groups (expressed as p-values in the post-hoc analyses) concerning the errors divided according to the presence and type of consonant clusters.

4.3.2.3 Phonological awareness

The percentage of correct answers in the phonological awareness tasks are displayed in Figure 4.5. As emerged from the figure, the syllabification task was very easy for all groups, resulting in a very few errors (for that reason this task has not been included in the statistical analyses). However, the other three tasks resulted overall very difficult. These tasks had been created to be mostly used with adults, and it resulted in a high number of mistakes in the control children group, too. Some of the children could not perform all the subtests, due to the difficulty in understanding the task. In particular, one child in the DD+SLI group could not perform the syllabic manipulation task, while one child in the DD+SLI group and four children in the DD-Only task could not perform the Spoonerism task.

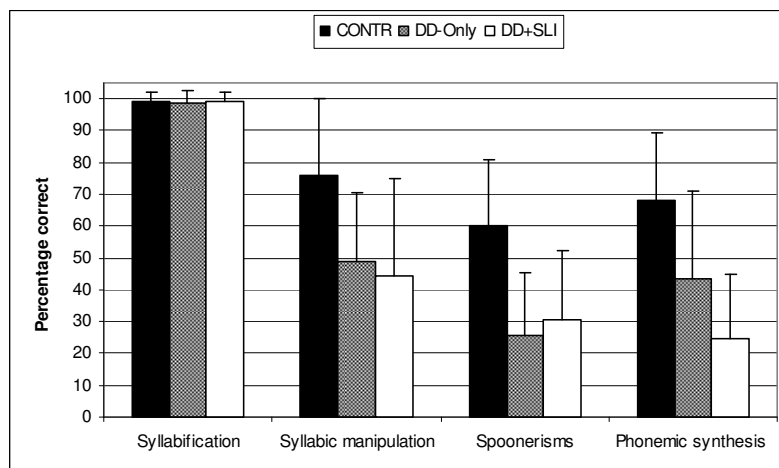


Figure 4.5: Percentage of correct answers in the Phonological awareness tasks

One-way ANOVAs were performed to estimate the differences between groups in the different tasks. The analyses showed significant group differences in all the tasks (Syllabic manipulation, $F(2,46) = 6.90$; $p < .005$; Spoonerisms, $F(2,42) = 12.19$; $p < .001$; Phonemic synthesis, $F(2,47) = 14.00$; $p < .001$)¹⁷. Post-hoc analyses (Tukey-HSD test) showed that the comparison between control children and children in both the dyslexic groups always reached statistical significance (all $p_s < .05$). Interestingly, the two dyslexic groups also differed in the Phonemic synthesis task, with DD+SLI children performing worse than DD-Only children, although the difference is only approaching significance ($p = .069$) (See the analyses on the distribution of single scores in Appendix 4A).

To check the reliability of this last result, further analyses were performed. In particular, we were interested in further investigating the different patterns between the dyslexic groups in tasks tapping phonological awareness at phonemic level. Failure to find a significant difference between the dyslexic groups in the Spoonerisms may be due to a floor effect, given the difficulty of this task, especially for children below 10 years (as already reported one child in the DD+SLI group and four children in the DD-Only task could not perform the task). Independent sample t-tests (comparing the DD-Only and DD+SLI groups) were thus performed only for children above 10 years. Nine children with DD-only and 8 children with DD+SLI were included in these additional analyses. The results confirmed those previously obtained in the overall sample. Only the difference between groups in the Phonemic synthesis task was significant, $t(15) = 2.71$, $p < .05$ (with higher scores in the DD-Only group, $M = 46.30$, $SD = 21.52$, with respect to the DD+SLI group, $M = 20.14$, $SD = 17.80$).

This result resembles that obtained in the verbal short-term memory tasks. Again, the additional WM load (in the Spoonerisms) had a negative impact on DD-Only performance. In this task the DD-Only's performance was similar to that of DD+SLI children. In contrast, in the phonemic synthesis task, where only STM was involved, DD-Only's performance improved, being significantly better than that of DD+SLI children,

For the Phonemic synthesis task, a different score was additionally computed, as the number of correctly pronounced phonemes (maximum score 69). The rationale of using this scoring (where each correctly repeated phonemes was assigned 1 point, instead of the previous scoring where each whole correctly repeated non-word was assigned 1 point) is that it does not penalise those children who had low scores in the phonemic synthesis task because repeated incorrectly only single phonemes. The results obtained with this scoring substantially replicated and reinforced the results obtained with the previous scoring (see Figure 4.6). A one-way ANOVA with Group as between-

¹⁷ All ANOVAs were significant also when applying the Bonferroni correction (setting α at 0.016).

subject factor revealed significant group differences, $F(2,44) = 8.98$; $p < .001$. Post-hoc analyses (Tukey-HSD test) showed significant differences between Control children and DD+SLI children ($p < .001$), but not DD-Only children ($p > .05$), while an additional significant difference was found between the two groups of dyslexic children ($p = .016$)¹⁸.

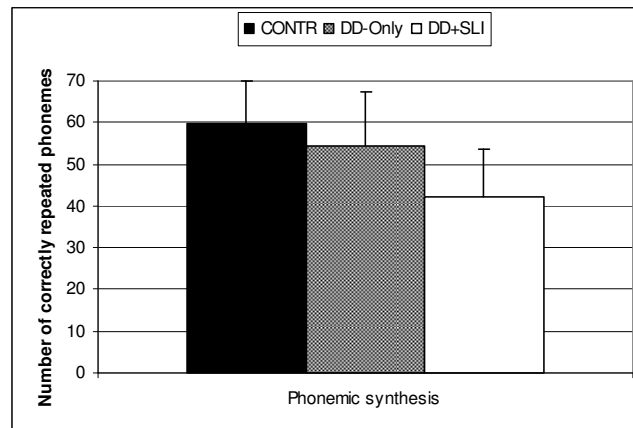


Figure 4.6: Number of correctly repeated phonemes in the Phonemic synthesis task

4.3.2.4 Correlations between phonological measures

Partial Pearson correlations (controlling for age) between phonological measures were computed for the whole sample (see Table 4.4). As emerged from the table, all measures are strongly correlated to each other.

	Digi. span (f)	Digit span (b)	N-word span	N-word rep.	Syll. manipul	Spoon.	Phon. synth.
Digit span (for.)	1						
Digit span (back.)	.379*	1					
Non-word span	.286	.277	1				
Non-word rep.	.401**	.512**	.418**	1			
Syll. Manipul.	.373*	.449**	.318*	.458**	1		
Spoon.	.443**	.671***	.396**	.459**	.668***	1	
Phon. synthesis	.570***	.434**	.396**	.487***	.451**	.683***	1

* < .05 ** < .01 *** < .001

Table 4.4. Partial Pearson correlations (controlling for age) between phonological measures

To avoid spurious effects in the correlations, separate partial Pearson correlations (controlling for age) were performed for each group, and are reported in Table 4.5. Similar patterns of correlation between phonological measures emerged in the control and the DD-Only group. In contrast, no

¹⁸ Interestingly, all the results presented in this Section were replicated when STM (estimated by monosyllabic non-word repetition) was entered as a covariate. This result further suggests that differences between groups are not only due to STM difficulties, but specifically related to phonological awareness skills.

correlations were found in the DD+SLI group, thus reflecting that phonological skills in this group are not related.

	Digi. span (f)	Digit span (b)	N-word span	N-word rep.	Syll. manipul	Spoon.	Phon. synth.
CONTROL PARTICIPANTS							
Digit span (for.)	1						
Digit span (back.)	.250	1					
Non-word span	-.328	-.120	1				
Non-word rep.	-.120	-.047	.583*	1			
Syll. manipul.	.541*	.360	-.158	-.003	1		
Spoon.	.383	.778***	-.363	-.238	.547*	1	
Phon. synthesis	.461	.116	-.438	-.047	.386	.505	1
DD-ONLY PARTICIPANTS							
Digit span (for.)	1						
Digit span (back.)	.244	1					
Non-word span	.402	.370	1				
Non-word rep.	.397	.657*	.017	1			
Syll. manipul.	-.118	.534	.168	.650*	1		
Spoon.	.188	.582*	.611*	.595*	.615*	1	
Phon. synthesis	.403	.145	.548	.357	.258	.701**	1

* < .05 ** < .01 *** < .001

Table 4.5. Partial Pearson correlations (controlling for age) between phonological measures in the control and DD-Only groups

Generally, the pattern of correlations is not easy to be interpreted. Additionally, a note of caution is warranted given the small number of participants in each group (N = 16) and the high number of correlations computed. Only a few qualitative observations on the general associations between phonological measures can be made (see notes in Table 4.6).

4.3.3 Discussion

Dyslexic children with and without additional language impairment have been compared to control children in different phonological variables (i.e., short-term memory, non-word repetition, phonological awareness). The results in the phonological tasks support the hypothesis of quantitative differences between dyslexic with and without additional language impairment. Dyslexic children with SLI generally show the worst performances, while children who present DD in the absence of SLI generally shows intermediate performances between DD+SLI children and control children. However, there are some results allowing to detect qualitative differences in the phonological performances of dyslexic children with and without SLI.

It should be noted that most of our phonological tasks involved different phonological competences. Table 4.6 provides an overview of the cognitive skills underlying the different tasks, and a summary of the results for each task.

While the performances of DD+SLI are always worse than those of control children, DD-Only children show performances not dissimilar from control children in those tasks involving only one skill (i.e., Digit span forward and Non-word repetition with shorter sequences). In addition, no differences between DD-Only and controls were found in Non-word repetition in the number of errors due to phonological complexity (in syllables with consonant clusters). DD-Only children's performance is worse when tasks become more difficult, and involve more skills. In particular, DD-Only children performed very differently from control children in repeating longer non-words (including both short-term memory and phonological processing skills), and generally in the phonological awareness tasks (generally involving additionally short-term and working memory skills). In some cases, DD-Only outperformed DD+SLI children (see conditions highlighted in Table 4.6), while in other cases DD-Only and DD+SLI children showed the same phonological impairment with respect to control children.

Interestingly, a significant interaction between DD-Only and DD+SLI groups emerged when considering phonological awareness at phonemic level, showing the existence of different qualitative profiles. DD-Only children had specific difficulties in the Spoonerisms, when phonemic awareness, short-term memory and working memory are involved, while they had better performances in the Phonemic synthesis task, when only phonemic awareness and short-term memory are involved. DD+SLI children, in contrast, had similar difficulties in the two tasks, without showing any improvement in the "easier" task.

Generally, the present results show that DD children with and without language impairment present different profiles of phonological deficit, with preserved competences in DD-only participants in the easier tasks, and additional impairment in verbal short-term memory and phonological processing in SLI participants. Similar conclusions were reached by other studies carried out on similar populations (Bishop et al., 2009; De Bree, 2007; Fraser et al., 2010; Nithart et al., 2009; Rispens, 2004; Wilsenach, 2006), mostly in Italian speaking children and young adults (Brizzolara et al., 2006; Chilosi et al., 2009; Lami, Palmieri, Solimando, & Pizzoli, 2009; Scuccimarra et al., 2008).

TASK	Involved skills¹⁹	Comparisons
Digit span forward	Short-term memory	CONTR > DD+SLI
Digit span backward	Short-term memory Working-memory	CONTR > DD-Only = DD+SLI
Monosyllabic non-word span	Short-term memory Phonological processing	CONTR > DD-Only = DD+SLI
Non-word repetition: 2 to 4 syllable sequences	Phonological processing	CONTR > DD+SLI
Non-word repetition 5 syllable sequences	Short-term memory Phonological processing	CONTR > DD-Only > DD+SLI
Non-word repetition: No cluster errors	Short-term memory Phonological processing	CONTR > DD-Only = DD+SLI
Non-word repetition: Cluster errors	Phonological processing	CONTR = DD-Only > DD+SLI
Syllabic manipulation	Phonological awareness Short-term memory	CONTR > DD-Only = DD+SLI
Spoonerisms	Phonemic awareness Short-term memory Working memory	CONTR > DD-Only = DD+SLI
Phonemic synthesis	Phonemic awareness Short-term memory	CONTR > DD-Only > DD+SLI

Table 4.6. Overview of the phonological tasks, the underlying involved skills, and the comparison between groups

Despite the number of differences between studies, particularly involving methodological issues such as criteria for the inclusion in the subgroups and experimental tasks, as well as degree of opacity of the language spoken by the participants, several similar findings can be determined. Rispens (2004) found exactly the same results reported in the present study. DD-Only children were not impaired in the easier Digit span forward task, while SLI were (Cntr = DD-Only > SLI). However, both in Digit span backward task and a test for phonemic awareness DD-Only and SLI children presented a similar impairment with respect to control children (Contr > DD-Only = SLI). Finally, in a non-word repetition task, DD-Only children performed more poorly than control children, but better than SLI children (Contr > DD-Only > SLI). Unfortunately, Rispens did not perform further analyses on the Non-word repetition task, and did not administer different tests of phonemic awareness, so qualitative differences between groups did not emerged in her study. Sophisticated analyses on a non-word repetition task were however performed by De Bree (2007) on a sample of children at-risk for DD, SLI children and control children, all aged 4. In particular,

¹⁹ The associations between phonological measures were confirmed by the patterns of correlations (see Table 4.4 and 4.5). Phonological awareness tasks generally correlated with each other, and with short-term memory measures as well. In particular, spoonerisms are related to working memory, as expressed by the high correlation in the control sample between this task and backward digit span. As expected, the non-word repetition task also involves short-term memory skills, as expressed by the correlation between these tasks.

the error pattern indicated that the SLI group performed more poorly but also differently than the control and the at-risk group (both phoneme and syllable omission and substitution increased more sharply as target length increased). Additionally, the performance of SLI children was generally affected more by target length. Similarly, in a French study, Nithart et al. (2009) found DD children with and without SLI to have both limited memory for sequences, while a more severe deficit in speech discrimination and short-term memory characterised dyslexic children with SLI. In particular, in their study, the performance of SLI children in a non-word repetition task appeared to decline as a function of the number of items on a list, earlier than the performance of both the control and dyslexic groups did.

Interestingly, in some of the studies, DD-Only children were only mildly affected in phonological processing tasks with respect to control children (Brizzolara et al., 2006; Chilosi et al., 2009; Scuccimarra et al., 2008). This anomalous result indicates that, at least in a subgroup of Italian dyslexic children, reading disabilities might occur in the absence of clear phonological working memory deficits. This is not the case of the present study, where DD-Only children were also impaired with respect to controls in complex measures of short-term and working memory, as well as in phonological awareness measures.

Similar to our findings, in most of the reported studies, the more severe phonological impairment in the DD group with additional SLI leads to similar patterns of reading impairment in the two dyslexic subgroups (Brizzolara et al., 2006; Chilosi et al., 2009; Joannis et al., 2000; Scuccimarra et al., 2008). Only in one study (Lami et al., 2009) more severe reading impairment has been found in DD+SLI children, while in Rispen's study (2004) SLI children overperformed DD-Only children in reading (it should be noted, however, the Rispen's inclusion criteria were different, and that only a subsample of her SLI children were also dyslexic).

Now that the data have been discussed and compared to the existing literature, the question remains what these can actually tell us about the **relationship between DD and SLI**. The data acquired in this experiment certainly show, as discussed above, that the same type of phonological deficits are present and that there is a difference in severity. In half of the tasks the DD+SLI children are outperformed by the dyslexic-only children, while in other tasks (particularly phonological awareness tasks) DD+SLI and DD-Only children perform the same. Qualitative differences have been however additionally found, showing that the phonological impairment is not only more severe in DD+SLI children, but also qualitatively different.

My personal hypothesis is that DD-Only children show difficulties when tasks are particularly complex, and involve different skills at the same time (phonological awareness involving additional short-term and working memory; backward digit span involving both short-term and working

memory and non-word repetition when also memory load is massive). This result seems coherent with the literature concerning a deficit in executive functions associated with DD (for recent evidence see Brosnan et al., 2002; Reiter, Tucha, & Lange, 2005). The term executive functions refer to a collection of cognitive abilities associated with the functioning of the prefrontal cortex. In general these functions are responsible for controlling and managing lower cognitive processes and are activated when several skills should be employed simultaneously. It could be hypothesised that the phonological performances of dyslexic-only children are due (or at least aggravated) by a deficit in executive functions. DD+SLI children, however, showed difficulties also when only one skill is specifically involved (short-term memory alone in the forward digit span, phonological processing alone in easier non-word repetition). It is however, difficult to draw firm conclusions about the exact relationship between the two syndromes based on these behavioural data.

So far, the results seem more consistent with the presence of qualitatively different phonological deficits underlying the two clinical samples, as in the framework of the *multiple overlapping risk factor model* (Pennington & Bishop, 2009). In an unpublished work (Marshall, Ramus, Rosen, Tang, & Van der Lely, unpublished), Marshall and colleagues came to a similar conclusion. Comparing dyslexic-only, SLI-only and dyslexic+SLI children, they found no clear-cut differences, either qualitative or quantitative, between the two disorders with respect to phonology. To explain the complex pattern of differences between groups they proposed a “*component model*” whereby the different components of language can break down independently. Within this framework, it is plausible to hypothesise that phonology can be divided into several subcomponents. DD and SLI might thus be characterised by different patterns of phonological impairments.

What seems particularly interesting is that, in the present experiment, different patterns of phonological deficits lead to a similar impairment in reading, but are associated with different performances in linguistic skills. Behavioural and electrophysiological data on non-phonological linguistic skills (Experiments 2 and 3) may thus provide more insight into the deficit(s) underlying DD and SLI.

4.4 Experiment 2: Behavioural characterisation of groups in linguistic skills

4.4.1 Assessment

4.4.1.1 Formal assessment of syntactic and semantic comprehension

- Grammatical comprehension: receptive grammatical skills were assessed with the “Test of Grammatical Comprehension for Children” (TCGB, "Test di Comprensione Grammaticale per i Bambini", Chilosi & Cipriani, 1995). Normative data for Italian are provided until 8 years of age. 76 sentences of increasing syntactic complexity were auditorily presented, and children were asked to match each sentence with one out of four pictures. Referring to the norms, z-scores were computed.
- Semantic comprehension: Semantic comprehension was assessed by administering the Italian version of the British Picture Vocabulary Scale (BPVS, De Agostini et al., 1998), which requires matching each of 25 words read out by the examiner with one out of four pictures (the target and three semantic distractors). Normative data for Italian are provided until 8 years of age. Referring to those norms, z-scores were computed.

4.3.1.2 Morphological, morphosyntactic and syntactic skills

In addition to the previously described tests, usually used for the formal assessment of linguistic skills in the clinical practice, the internal-use battery Co.Si.Mo ("Competenze Sintattiche e Morfosintattiche", Syntactic and Morphosyntactic skills, Milani et al., 2005) was administered. It covers different areas of morphological and (morpho)syntactic development, both in production and in comprehension. In contrast to other standardised tests on language skills that specifically investigate explicit skills formally learned at school, the battery Co.Si.Mo additionally addresses implicit morphosyntactic knowledge. In most of the tasks, children were in fact asked to induce the rule to be applied from examples. Additionally, the use of non-words in the morphosyntactic subtests prevented from the mere retrieval of morphologically complex forms stored as whole-forms. Wide and consistent normative data are provided from 2nd primary school grade to 3rd secondary school grade. From the whole battery, six tasks were selected to be administered, and both raw and z-scores were computed for each subtest. Additionally, in order to make all the subtest scores comparable, percentages of correct answers were computed for each tasks.

- Plural formation (words): Children were auditorily presented with words in the singular form (and their respective determiner) and they were asked to produce the plural forms (both noun and determiner). For example, ‘l-a cas-a’ (the-S house-S) should become ‘l-e cas-e’ (the-P houses-P). One point was assigned for each correct answer (both determiner and noun correct), while 0.5 points were assigned when only the noun was correctly produced.
- Plural formation (non-words): The same task was performed with non-word stimuli (for example ‘l-a tomeg-a’ should become ‘l-e tomeg-e’).
- Morphological manipulation (non-words): Children were both auditorily and visually presented with non-words. The production of different morphological manipulations of non-words was requested. Some of the non-words were noun-like, and in these cases manipulations involved the creation of plural forms (for example, ‘brip-o’ should become ‘brip-i’), diminutive and augmentative forms (for example, ‘brip-ino’ or ‘brip-one’), and other kinds of manipulations existing in Italian. Two of the non-words (requiring 4 manipulations each) were verb-like, presented as past participle or simple present forms. In these cases, manipulations involved the creation of the infinitive form (for example, ‘ho senc-ato’ should become ‘senc-are’), the substantive form (‘senc-atore’), or other manipulations involving different persons or tenses (involving gerundive and conditional forms). On the whole, the subtest included 22 manipulations. One point was assigned for each correct answer, while 0.5 points were assigned for other neologisms correctly formulated (for example: “brip-ino” is the right diminutive of “brip-o” [1 point], while “brip-etto” is worth 0.5 points).
- Syntactic comprehension: Sentences with complex syntactic structures were auditorily presented, and children were asked to point to the picture better representing the sentence. The target picture was always presented with two distractors, containing the same elements but in different relationship. For example, for the sentence “*la scarpa nella borsa bianca è rotta*” (*the shoe in the white bag is broken*) the two distractor pictures represented a broken shoe in a black bag and a white shoe in a broken bag. The subtest included five items, and one point was assigned when the child pointed to the correct picture.
- Word order comprehension: Pairs of sentences were auditorily presented. Both sentences in each pair contained identical words but in different orders (for example: “*il bambino ha rotto il vaso di cui ti ho parlato*” [*the child has broken the pot about which I spoke to you*] vs. “*il bambino di cui ti ho parlato ha rotto il vaso*” [*the child about whom I spoke to you has broken the pot*]). Children were asked to decide whether the two sentences had the same meaning or not. The subtest included five items, and one point was assigned for each correct answer.

- **Production of clitics and pronouns:** Pairs of sentences were auditorily presented. The first sentence comprised all full substantives, while in the second sentence two substantives were replaced with clitic pronouns (for example: “*La nonna racconta la storia al bambino*” [*Granma tells the story to the child*] vs. “*La nonna glie-la racconta*” [*Granma tells it to him*]). Children were asked to judge the correctness of the transformation, and in case of wrong transformation (for example, “*La nonna me-la racconta*” [*Granma tells it to me*]), they were asked to correct the second sentence. The subtest included seven items, and 0.5 points were assigned for each correct judgement, while one point was assigned for each correct transformation.

Based on the norms, four composite indexes were additionally created: Nominal morphology (summing scores obtained in the Plural formation subtests, both words and non-words, and scores in the Morphological manipulation, considering only manipulations of noun-like non-words); Verbal morphology (considering only manipulations of verb-like non-words in the Morphological manipulation subtest), Free morphology (subtest of Production of clitics and pronouns), and Inflectional morphology (summing scores obtained in the Plural formation subtests, both words and non-words, and scores in the Morphological manipulation subtest). For all the indexes, raw scores, z-scores were computed, as well as percentages of correct answers.

4.4.1.3 Grammaticality judgement

The same material and task-specific procedure described in Section 3.2.3 were used.

4.4.2 Results

4.4.2.1 Formal assessment of semantic and syntactic comprehension

As already reported in Table 4.1, a one-way ANOVA was performed concerning language skills as normally assessed in the clinical practice. Concerning the Syntactic comprehension task (TCGB, Chilosi & Cipriani, 1995), an overall difference between groups was found, that was driven by the DD+SLI group, differing from both the Control and the DD-Only group. A similar pattern, although not significant, was found for the semantic comprehension task (British, De Agostini et al., 1998). Figure 4.7 displays the distribution of z-scores in the syntactic and semantic comprehension task.

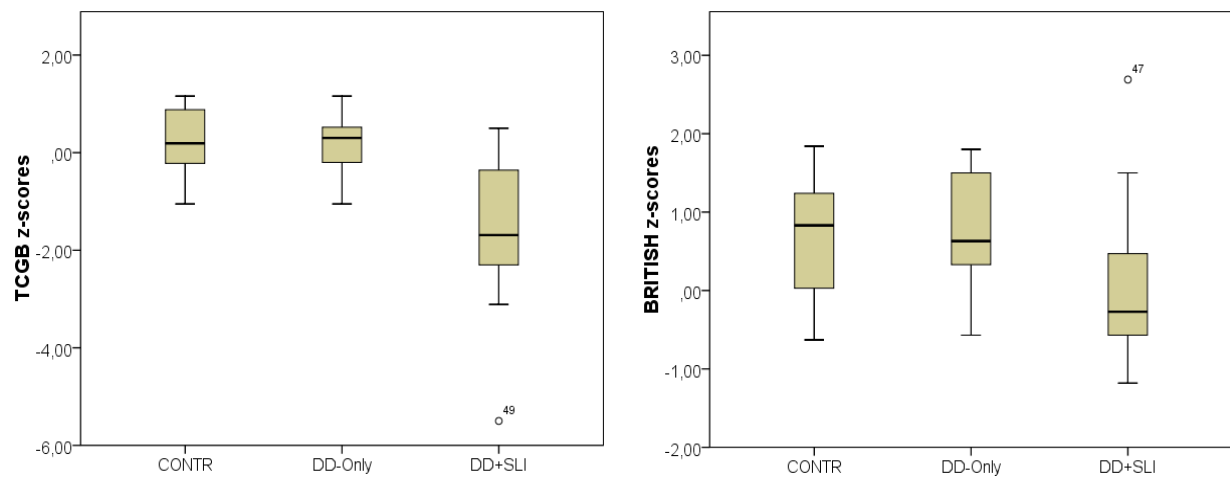


Figure 4.7: Distribution of z-scores in the syntactic comprehension task (TCGB; left) and the semantic comprehension task (right)

Given the presence of outliers in the DD+SLI group, separate one-way ANOVAs were repeated without the outliers. For the TCGB task, the overall group difference was still significant $F(2,41) = 14.21$; $p < .001$, and post-hoc analyses (Tukey-HSD test) still revealed a significant difference between the DD+SLI group and the control group ($p < .001$) and the DD-Only group ($p < .001$), but not between the DD-Only group and the control group ($p = .984$). For the semantic comprehension task, the overall group difference was now significant $F(2,41) = 6.38$; $p = .005$, and post-hoc analyses (Tukey-HSD test) revealed a significant difference between the DD+SLI group and the control group ($p < .05$) and the DD-Only group ($p < .01$), but not between the DD-Only group and the control group ($p = .955$). These results showed that the two tests were both able to identify the language difficulties in the DD-SLI group.

4.4.2.2 Morphological, morphosyntactic and syntactic skills

The percentage of correct answers in the morphological and (morpho)syntactic tasks (Co.Si.Mo battery) are displayed in Figure 4.8 and Figure 4.9.

One-way ANOVAs were performed to investigate Group differences on each task. Main effect of Group emerged for all tasks (all $p_s < .005$), except for Syntactic comprehension, $F(2,47) = 2.45$; $p = .098$, and Word order comprehension, $F(2,47) = .307$; $p > .05$ ²⁰.

²⁰ All ANOVAs were significant also when applying the Bonferroni correction (setting α at 0.008), except the ANOVAs performed for Syntactic comprehension and Word order comprehension

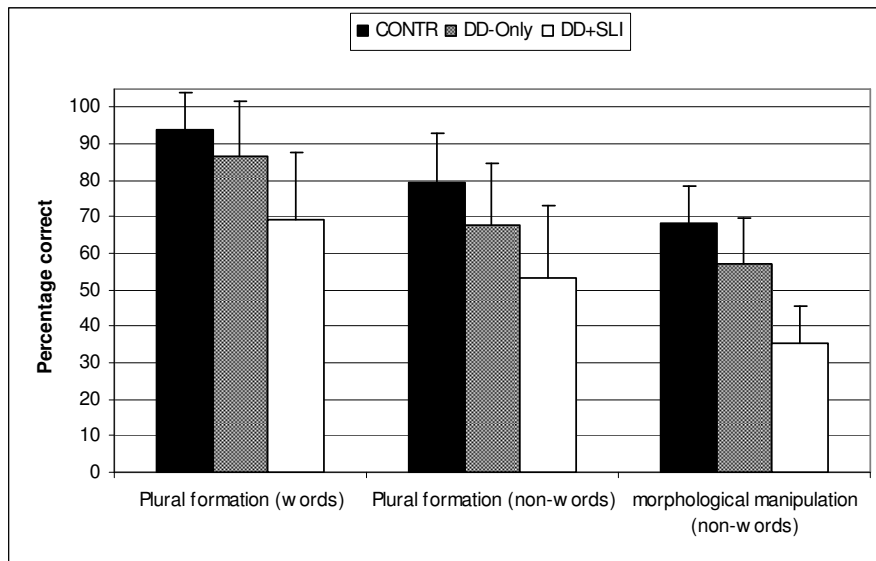


Figure 4.8: Percentage of correct answers in the tasks requiring to produce morphological inflections

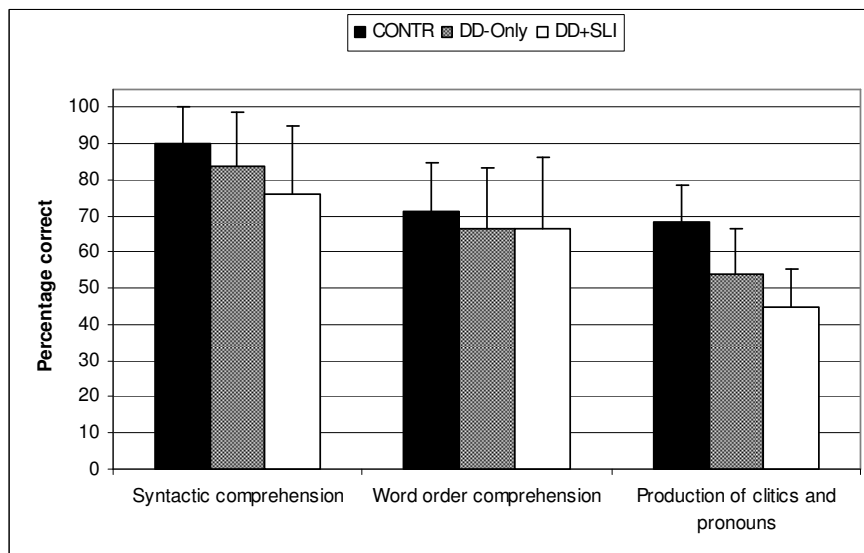


Figure 4.9: Percentage of correct answers in the syntactic and morphosyntactic subtests

Post-hoc analyses (Tukey-HSD test) for the significant one-way ANOVA comparisons are reported in Table 4.7. As expected, significant differences between the control group and the DD+SLI group were found for all tasks. In addition, the difference between DD-Only and DD+SLI children is significant for the plural formation (words) task and the morphological manipulation (non-words) task. For the latter task, the difference between the control group and the DD-Only group also emerged, showing a specific morphosyntactic impairment in those children who do not have any formal diagnoses of language impairment²¹.

²¹ In order to further quantify the presence of difficulties in the two dyslexic groups the distribution of scores in the normal population (as provided by the norms of the test) was taken as a reference. Reflecting our recruitment criteria, only a few DD-Only children had sporadically scores below 2 SD. However, proportions of scores ranging between 1

COMPARISON	Plural formation (words)	Plural formation (non-words)	Morphological manipulation (non-words)	Production of clitics and pronouns
CONTR vs. DD-ONLY	.363	.152	.020	.078
CONTR vs. DD+SLI	<.001	<.001	<.001	.002
DD-ONLY vs. DD+SLI	.006	.051	<.001	.338

Table 4.7. Differences between groups (expressed as p-values in the post-hoc analyses) concerning morphological and morphosyntactic tasks

Further analyses were thus performed taking the composite indexes provided from the normative data into account. In this case, raw scores were converted into z-scores, in order to make the tasks comparable. Two sets of analyses were performed.

First, Nominal morphology and Verbal morphology in the three groups were compared. An overall repeated measure ANOVA was conducted, with Stimulus as within-subject factor (noun vs. verb) and Group as between-subject factor. Only a main effect of Group $F(2,44) = 47.24; p < .001$ emerged, while the main effect of Stimulus, and the Stimulus * Group interaction were not significant, $F(1,44) = 0.92; p > .05$ and $F(2,44) = 0.59; p > .05$, respectively. Then, Free morphology and Inflectional morphology in the three groups were compared. An overall repeated measure ANOVA was conducted, with Type as within-subject factor (free vs. inflectional) and Group as between-subject factor. A main effect of Type, $F(1,43) = 46.66; p < .001$, and a main effect of Group $F(2,43) = 22.42; p < .001$ emerged, as well as a significant Type * Group interaction, $F(2,43) = 8.22; p > .005$. Both the interactions are displayed in Figure 4.10.

In both cases, Post-hoc analyses (Tukey-HSD test) revealed significant differences between the control group and both the DD+SLI group (both $p_s < .001$) and the DD-Only group (both $p_s < .05$), as well as between the two dyslexic groups (both $p_s < .001$). In the analysis concerning Free and Inflectional morphology, the main effect of Type was driven by the overall lower performances in Inflectional morphology ($M = -1.53; SD = 1.37$) with respect to Free morphology ($M = -0.59; SD = 0.97$), $t(45) = 5.73, p < .001$. The Type * Group interaction reflected that the difference between

and 2 SD below the norm were quite high (6,3% in the plural formation [words]; 12,5% in plural formation [non-words], morphological manipulation [non-words], and syntactic comprehension; 31,25% in production of clitics and pronouns and 50% in word order comprehension). In the DD+SLI group, proportions of scores below 2 SD were higher (31,3% in the plural formation [words]; 25% in plural formation [non-words]; 68,8% in morphological manipulation [non-words], 21,4% in production of clitics and pronouns, only 12,5% in word order comprehension and 6,3% in syntactic comprehension). The proportion of children between 1 and 2 SD were however low (ranging from 12 to 18%), but was higher in production of clitics and pronouns (37,5%). The distributions in the two groups were statistically different only for the Plural formation (words), $\chi(2) = .042$, and in the morphological manipulation (non-words), $\chi(2) = .001$.

Free and Inflectional morphology was higher in the DD+SLI group, $t(13) = -3.21, p < .001$, than in the DD-Only and in the Control groups, $t(15) = 2.88, p < .05$ and $t(15) = 2.12, p = .051$, respectively (but significant in each group).

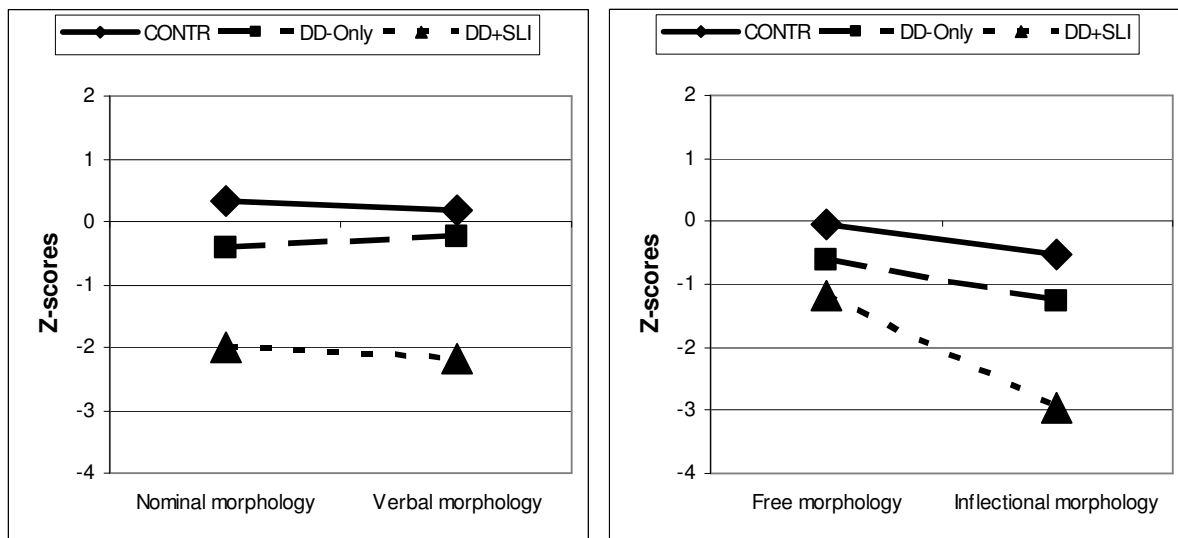


Figure 4.10. Scores in the composite indexes calculated for Nominal and Verbal morphology (left) and for Free and Inflectional morphology (right)

The present results revealed that the linguistic deficit identified in the DD-Only group seems to reflect quantitative differences with respect to the control children's performance, while the linguistic deficit characterising the DD+SLI children reflects both quantitative and qualitative differences with respect to both control and DD-Only children. Moreover, some additional remarks should be advanced concerning DD-Only children's performances. The fact that DD-Only children differ from controls specifically when manipulations of non-words are required strengthens the possibility that the strategies used by DD-Only children to resolve the task involve more lexical skills than morphological skills.

4.4.2.3 Grammaticality judgement

The results of the grammaticality judgement task in terms of accuracy are presented in Figure 4.11. Two separate repeated measure analyses of variance (ANOVAs) were performed, one for the experimental sentences (containing subject-verb agreement violations) and one for the filler sentences (containing violations in the choice of the auxiliary). In both ANOVAs the between-subject factor Group (control children vs. DD-Only children vs. DD+SLI children) and the within-subject factor Grammaticality (correct vs. incorrect) were defined for analysis.

The ANOVA performed on the experimental sentences yielded a main effect of Group, $F(2,45)$

= 6.98, $p < .005$, while neither the main effect of Grammaticality nor the interaction Grammaticality * Group reached statistical significance, $F(1,45) = 0.07$, $p > .05$ and $F(2,45) = 0.64$, $p > .05$, respectively Post-hoc analyses (Tukey-HSD test) revealed significant differences between the DD+SLI group and the control group ($p = .0021$), Interestingly, a difference approaching significance emerged between the control group and the DD-Only group ($p = .065$). However, no differences emerged between the two dyslexic groups ($p = .356$).

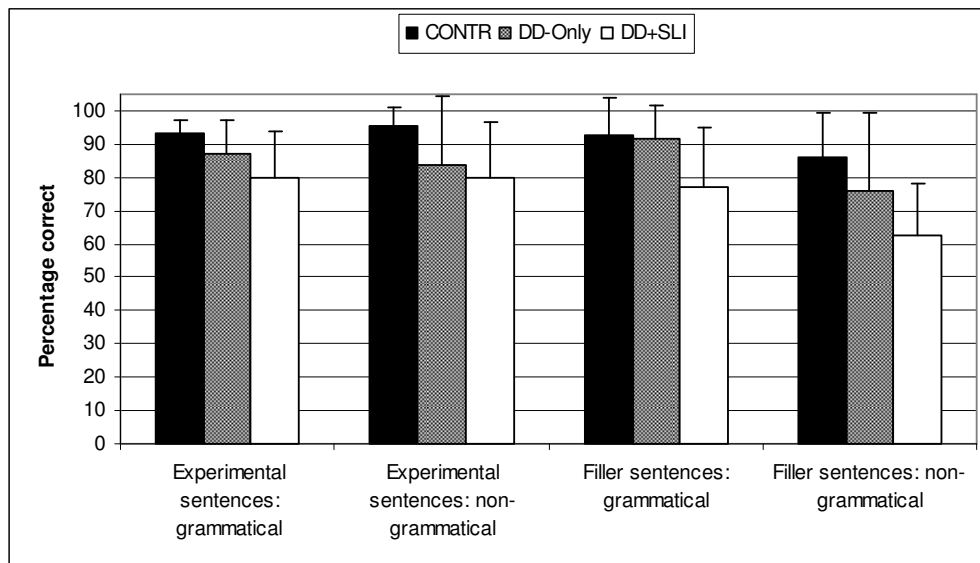


Figure 4.11: Percentage of correct answers in the grammaticality judgement task

The ANOVA performed on the filler sentences yielded a main effect of Group, $F(2,45) = 12.71$, $p < .001$, and Grammaticality, $F(1,45) = 15.11$, $p < .001$, while the interaction Grammaticality * Group was not significant, $F(2,45) = 0.73$, $p > .05$. Post-hoc analyses (Tukey-HSD test) revealed significant differences between the DD+SLI group and both the control group ($p < .001$) and the DD-Only group ($p < .005$), while no differences emerged between the control group and the DD-Only group ($p = .345$). The main effect of Grammaticality was explained by an overall better performance in judging the correct ($M = 87.14$, $SD = 15.07$) vs. the incorrect ($M = 74.70$, $SD = 20.25$) sentences (See the analyses on the distribution of single scores in Appendix 4A).

4.4.2.4 Correlations between phonological, morphological and (morpho)syntactic skill

Overall partial Pearson correlations (controlling for age) between phonological, morphological and (morpho)syntactic measures (as estimated by the Co.Si.Mo battery and by the grammaticality judgement task) are reported in Table 4.8. As emerges from the table, all morphological measures and, to a lesser degree, morphosyntactic measures (including grammaticality judgement) are

correlated to phonological measures, while pure syntactic measures are not.

	Digi. span (f)	Digit span (b)	N-word span	N-word rep.	Syll. manipul	Spoon.	Phon. synth.
Plural form. (w.)	.166	.319*	.426**	.298	.309*	.374*	.624***
Plural form.(n-w.)	.220	.237	.387*	.374*	.476**	.468**	.374*
Morph. manipul	.479**	.455**	.415**	.640***	.454**	.610***	.734***
Syntactic compr.	-.010	.161	.035	-.005	.109	.198	.151
Word-order comp.	.077	.175	-.128	.022	.235	.203	.224
Pronouns	.497***	.464**	.103	.539***	.244	.356*	.417**
Subject-verb agr.	.267	.341*	.209	.347*	.197	.327*	.410**
Auxiliary selection	.263	.331*	.202	.406**	.126	.200	.398**

* < .05 ** < .01 *** < .001

Table 4.8. Pearson correlations between phonological and (morpho)syntactic measures

To avoid spurious effects in the correlations, separate partial Pearson correlations (controlling for age) were performed for each group including only morphological and morphosyntactic measures. Only the few significant correlations are reported in Table 4.9.

	Digit span (b)	N-word rep.	Syll. manipul	Spoon.	Phon. synth.
CONTROL PARTICIPANTS					
Morph. manipul				.536*	
Pronouns	.578*				
Subject-verb agr.	.542*				.583*
DD-ONLY PARTICIPANTS					
Morph. manipul		.554*		.639*	.774**
DD+SLI PARTICIPANTS					
Plural form. (w.)					.802**
Plural form.(n-w.)			.696*		

* < .05 ** < .01 *** < .001

Table 4.9. Partial Pearson correlations between phonological and (morpho)syntactic measures in the three groups (only significant correlations are reported)

As observed before, a note of caution is warranted, given the small number of participants in each group (N = 16) and the high number of correlations computed. Only a few qualitative observations can be made. The patterns of correlation emerging when separate groups were considered are less consistent with respect to correlations in the whole sample. Generally, the task requiring to produce morphological manipulations of non-words was the more related to different

phonological measures, and mainly to phonological awareness measures. This is particularly strong in the DD-Only group. Sensitivity to morphosyntactic violations (as expressed by performances in the grammaticality judgement task) were correlated to phonological measures only in the control group.

4.4.3 Discussion

Dyslexic children with and without additional language impairment have been compared to control children in different language variables (i.e., semantic comprehension, syntactic comprehension, production of inflectional morphology, and sensitivity to violations through a grammaticality judgement task). The most interesting finding concerns the presence of subtle linguistic deficits in the DD-Only children. Although these children do not have any formal diagnosis of language impairment, they show linguistic difficulties when particular sensitive instruments are used. The presence of linguistic deficits involving different linguistic domains in apparently “pure” dyslexic individuals (i.e., comprehension and production of complex syntactic structures and inflectional morphology) has been widely reported in the literature (Altmann et al., 2008; Barshalom et al., 1993; Joanisse et al., 2000; Leikin & Assayag-Bouskila, 2004; Leikin & Hagit, 2006; P. Lyytinen et al., 2001; Mann et al., 1984; Rispens & Been, 2007; Rispens et al., 2004; Robertson & Joanisse, 2010; Scarborough, 1990; Smith et al., 1989; C. L. Stein et al., 1984; van Alphen et al., 2004; Waltzman & Cairns, 2000; Wilsenach, 2006; Wiseheart et al., 2009), as systematically reviewed in chapter 1.

In the present study, DD-Only children are specifically impaired in the production of inflectional morphology, while the comprehension of syntactically complex structures seems preserved. Other studies have investigated the production of inflectional morphology particularly showing that children and adults with DD experience difficulties in the production of regular and irregular past tense in English (Altmann et al., 2008; Joanisse et al., 2000). In the present study, however, the difficulty involves both nominal and verbal morphology. These results might be explained by intrinsic features of the task (presenting more items for nominal morphology than verbal morphology), as well as by the characteristic of Italian, that presents a richer nominal morphology with respect to English. In a study conducted by van Alphen et al. (2004) in Dutch, another language with richer nominal morphology than English, in fact, children at risk for DD (aged 3 years old) produced fewer inflected verbs as well as fewer plural form of nouns with respect to aged-matched control children.

Another noteworthy point concerns the nature of the morphosyntactic deficit in the DD-Only

children. The performance of these children differ from those of controls specifically when manipulations of non-words are required, and thus when there is no meaningful verbal information that can help in solving the task. In this regard, strategies used by DD-Only children to produce morphological transformations might involve more lexical skills than purely morphological skills. This point concerning the cognitive strategy that is used by children to resolve the task might be better addressed in the following section, where an online methodology (ERPs) will be used to investigate morphosyntactic processing.

In general, the finding of the presence of linguistic difficulties in DD-Only children entails two kinds of implications.

The first one concerns the way to assess linguistic skills in school-aged children. In her doctoral dissertation, Rispens (2004) has already underlined the important role of the methodology in the assessment of morphosyntactic difficulties in DD children. The absence of sensitive standardised tests to assess linguistic skills in school-aged children, at least in Italian, might in fact underestimate the degree of comorbidity between reading and language impairment.

The second implication is more related to the theoretical issue of the overlap between DD and SLI. As already discussed (see Section 1.3.2) none of the hypotheses on the relationship between developmental dyslexia and SLI offers an adequate explanation for the presence of non-phonological linguistic difficulties in DD. All hypotheses just describe phonological difficulties in DD, thus rising the question whether the subtle linguistic deficit found in DD might only be a consequence of the phonological impairment.

The question has already been addressed by several scholars, for what concerns both DD and SLI's linguistic deficits. As reviewed in chapter 1, the '*processing limitation hypothesis*' proposed by Shankweiler and Crain (1986) claims that syntactic deficits in DD are caused by an underlying phonological deficit in short-term or working memory, that impedes the temporary storage of verbal material. This hypothesis was supported by several studies, indicating relationship between poor STM and WM skills and both syntactic (Barshalom et al., 1993; Leikin & Assayag-Bouskila, 2004; Mann et al., 1984; Robertson & Joanisse, 2010; Smith et al., 1989; van Alphen et al., 2004; Wiseheart et al., 2009) and morphosyntactic (Jiménez et al., 2004; Rispens & Been, 2007) comprehension.

Rispens and Been (2007) based their conclusion that the morphosyntactic difficulties in DD were related to the phonological impairment upon the presence of a significant correlation between sensitivity to subject-verb agreement violations and verbal short-term memory (expressed by non-word repetition). The same correlation has been found in the previous study when considering the overall sample. However, it is probably due to spurious effects, as it disappears when separate

groups are considered. The presence in our study of other significant correlations, particularly significant in the DD-Only group, between morphological manipulations of non-words and different kinds of phonological processing measures leaves the door open to the possibility that the morphosyntactic difficulties in DD are, at least in part, due to phonological difficulties.

From a slightly different perspective, Joanisse and colleagues (2000) attributed the morphosyntactic problems highlighted in their sample of children with DD (particularly concerning the lack of complete acquisition of morphological patterns) to a phonological impairment of different nature with respect to that proposed by Shankweiler and Crain (1986). In particular, Joanisse proposed a phonological segmental deficit affecting the acquisition and generalisation of morphological patterns. In our specific case, this problem in segmental phonology does not seem to be crucial in DD-Only children, given the results in the Non-word repetition task. As already discussed, these children have performances similar to controls when repeating syllables containing difficult consonant clusters. However, the relationship between segmental phonology and morphosyntactic acquisition will be addressed in Chapter 5, taking advantage of the linguistic features characterising German.

4.5 Experiment 3: Electrophysiological correlates of subject-verb agreement violations

4.5.1 Experimental procedure and EEG data acquisition

The same material and task-specific procedure described in Sections 3.2.3. were used. Particular expedients were adopted to record more reliable ERP data with children. EEG data were recorded from 19 Ag/AgCl electrodes placed according to the international 10-20 system (Jasper, 1958) at the following positions: FP1/2, F7/8, F3/4, Fz, T7/8, C3/4, Cz, P7/8, P3/4, Pz, O1/2. Blinks and vertical eyes movements (VEOG) were monitored using two electrodes that were placed above and below the right eye. Horizontal eye movements (HEOG) were recorded from two electrodes located at the outer left and right canthi of the eyes. Additionally, EEG signal was recorded from short-circuit electrodes placed on the right and left mastoids, and the obtained signal was used as online reference. A further electrode placed on the participant's forehead served as ground electrode. All electrode impedances were kept below 10 k Ω . All electrodes were connected to a Neuroscan amplifier (SynAmps vers. 1, Compumedics). EEG signal was digitalised at the rate of 1000 Hz.

After recording, the EEG signal was bandpass zero-phase filtered at 0.3-40 Hz. The continuous EEG signal was then processed with an automatic rejection criterion applied to all electrodes (sections exceeding 70 μV were excluded). All ERPs were time-locked to the onset of the critical morpheme, and calculated with respect to a pre-stimulus baseline of 100 ms for an epoch of 1200 ms.

4.5.2 Results

The ERP data for the incorrect versus the correct condition are displayed in Figures 4.12. The subject-number agreement violation displays different component in the three groups. Generally, a broadly distributed Negativity can be identified in the dyslexic groups, while a centro-posterior Positivity emerged in the Control Group and in the DD+SLI group.

4.5.2.1 Data analysis

Two Time Windows (TWs) were selected, according to the literature and after an accurate inspection of the Grand Averages: 250-550 and 700-1000 ms. Separate repeated measure ANOVAs concerning the ERP mean amplitude were performed for each TW. The between-subject factor Group (control children vs. DD-Only children vs. DD+SLI children) and three within-subject factors (Grammaticality: correct vs. incorrect; Hemisphere: left vs. right; Region: anterior vs. central vs. posterior) were defined for analysis of data from 12 lateral electrodes. The variables Hemisphere and Region were completely crossed, yielding six Regions of Interest (ROIs), each of which had two electrodes: Left Anterior (F7 and F3), Right Anterior (F4 and F8), Left central (T7 and C3), Right Central (C4 and T8), Left Posterior (P3 and P7) and Right Anterior (P4 and P8). Additionally, separate analyses were performed for the three midline electrodes (Fz, Cz and Pz). Again, separate repeated measure ANOVAs concerning the ERP mean amplitude were performed for each TW. In this case, the between-subject factor Group and two within-subject factors (Grammaticality and Region) were defined for analysis.

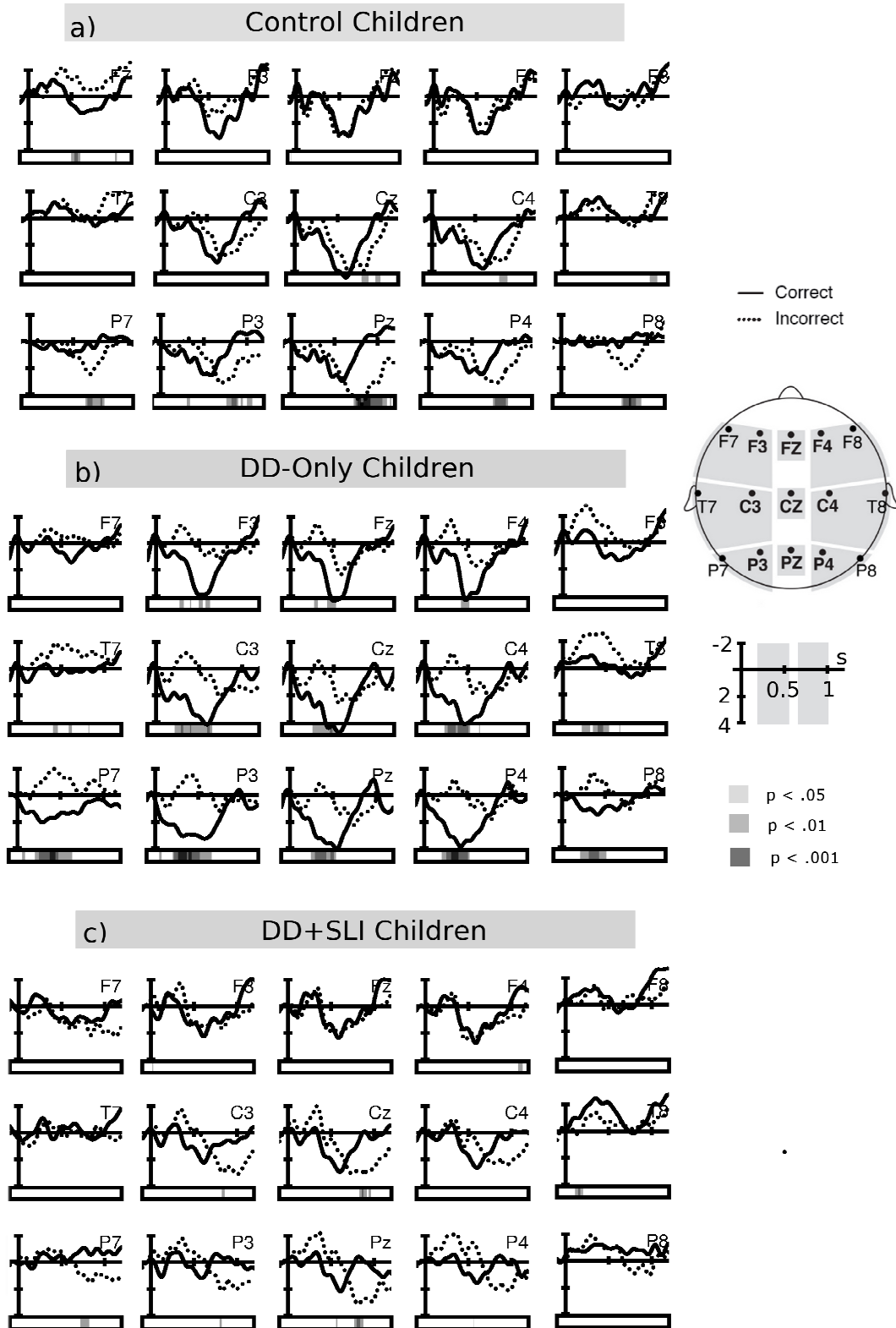


Figure 4.12. Grand average ERPs of the control (a) and DD-Only (B) and DD+SLI children. The morpho-syntactically incorrect condition (dot line) is plotted against the correct condition (continuous line). The axis of the ordinates indicates the onset of the suffix. The grey sections under the graphs refer to statistically significant t-test performed on picks. Negative voltage is plotted upward. The plots have been filtered with a 5-Hz low-pass filter for presentation purpose only.

4.5.2.2 Time-window 250-550 ms

The results of the main analyses concerning lateral electrodes are reported in Table 4.10.

	df	Lateral Electrodes F	p-value
Grammaticality	1,45	15.62	< .001
Gram. * Group	2,45	5.65	< .001
Gram * Hemisphere	1,45	< .1	
Gram * Hemisphere * Group	2,45	< .1	
Gram * Region	2,88	1.75	NS
Gram * Region * Group	4,88	< .1	
Gram * Hemisphere * Region	2,88	< .1	NS
Gram * Hemisphere * Region * Group	2,48	2.40	.056

Table 4.10: Global analyses of ERP data at lateral electrodes (TW 250-550)

A main effect of Grammaticality emerges, indicating the presence of a statistically significant component, that is broadly distributed, given the non-significant interactions Grammaticality * Hemisphere and Grammaticality * Region. Interestingly, the interaction Grammaticality * Group is statistically significant. According to this result, further analyses in this time-window were performed. Separate ANOVAs for groups revealed a main effect of Grammaticality only in the DD-Only group, $F(1,15) = 14.815$, $p < .005$, and not in the control group, $F(1,15) = 1.42$, $p > .05$, and in the DD+SLI group, $F(1,15) = 1.14$, $p > .05$. In the DD-Only group, the interactions Grammaticality * Hemisphere, Grammaticality * Region, and Grammaticality * Hemisphere * Region were not significant (all $ps > .05$), confirming the broadly distribution of the component. Interestingly, the three-level interaction Grammaticality * Hemisphere * Region was significant in the control group, $F(2,30) = 5.11$, $p < .05$. Due to this interaction, correct and incorrect conditions in the control group were compared for each ROI. Table 4.11 reports the results of paired t-test comparisons. Although no comparison reached statistical significance, there is a tendency approaching significance (at one-way p-value, given the unidirectional hypothesis) at left side.

ROI	t(15)	p-value	ROI	t(15)	p-value
AL	1.73	.104	AR	< 1	
CL	1.70	.110	CR	< 1	
PL	1.73	.103	PR	1.207	NS

Table 4.11: Paired t-test comparisons between correct and incorrect condition for each ROI in the control group (TW 250-550)

The same analysis was repeated at midline electrodes, showing a similar pattern. The results of the main analyses concerning midline electrodes are reported in Table 5.12.

	df	Midline electrodes F	p-value
Grammaticality	1,45	17.405	< .001
Gram. * Group	2,45	3.801	< .05
Gram * Region	2,88	3.754	< .05
Gram * Region * Group	4,88	< 1	

Table 4.12: Global analyses of ERP data at midline electrodes (TW 250-550)

A main effect of Grammaticality emerges, indicating the presence of a statistically significant component. At midline electrodes, the interaction Grammaticality * Region was also significant, indicating a different distribution of the component. Paired t-tests in the three electrodes revealed a posterior localisation of the component (Fz, $t(46) = 1.86$, $p = .070$; Cz, $t(46) = 4.06$, $p < .001$; Pz, $t(46) = 4.38$, $p < .001$). The interaction Grammaticality * Group was again also significant. According to this result, further separate ANOVAs for groups revealed a main effect of Grammaticality only in the DD-Only group, $F(1,15) = 13.87$, $p < .005$, and not in the control group, $F(1,15) = 1.28$, $p > .05$. At midline electrodes, the DD+SLI group also showed an effect to Grammaticality approaching significance $F(1,15) = 3.75$, $p = .072$, that reached significance considering the interaction Grammaticality * Region, $F(2,39) = 3.62$, $p < .05$. Paired t-test performed in the DD+SLI group only, showed the posterior localisation of this component (Fz, $t(15) < 1$; Cz, $t(15) = 2.47$, $p < .05$; Pz, $t(15) = 2.58$, $p < .05$). In the DD-Only group, the interaction Grammaticality * Region was not significant, $F(2,30) = 0.14$, $p > .05$, again confirming the broadly distribution of the component.

4.5.2.3 Time-window 700-1000 ms

The results of the main analyses are reported in Table 4.13. As the main effect of Grammaticality does not emerge, the significant interaction with Region indicates the existence of a component differently distributed on the scalp. Paired t-tests were then performed to compare correct and incorrect conditions in different regions, generally showing a posterior localisation (Ant, $t(47) = .354$, $p > .05$; Cen, $t(47) = -.985$, $p > .05$; Pos, $t(47) = -2.74$, $p < .01$).

	Df	Lateral Electrodes	
		F	p-value
Grammaticality	1,45	1.56	NS
Gram. * Group	2,45	< 1	
Gram * Hemisphere	1,45	< 1	
Gram * Hemisphere * Group	2,45	< 1	
Gram * Region	2,88	9.36	< .001
Gram * Region * Group	4,88	1.75	NS
Gram * Hemisphere * Region	2,88	< 1	
Gram * Hemisphere * Region * Group	2,48	1.21	NS

Table 4.13: Global analyses of ERP data at lateral electrodes (TW 700-1000 ms)

Despite the absence of interaction with Group, separate ANOVAs for groups were performed. In the control group, no significant effect of Grammaticality emerged, $F(1,15) = 0.91$, $p > .05$, but a significant interaction Grammaticality * Region emerged $F(2,30) = 12.58$, $p < .001$. Again, paired t-tests revealed that the component was significant only in posterior region, $t(15) = -2.80$, $p < .05$). Similarly, in the DD+SLI group, no significant effect of Grammaticality, $F(1,15) = 2.78$, $p > .05$, but an interaction Grammaticality * Region approaching significance, $F(2,30) = 3.249$, $p = .053$, emerged. Again, paired t-tests revealed that the component was significant only in posterior region ($t(15) = -2.70$, $p < .05$). Differently, no main effect or interaction emerged in the DD-Only group, showing the complete absence of this component in the group.

The same analysis was repeated at midline electrodes, showing a similar pattern. The results of the main analyses concerning midline electrodes are reported in Table 4.14.

	df	Midline electrodes	
		F	p-value
Grammaticality	1,45	7.46	< .01
Gram. * Group	2,45	< 1	
Gram * Region	2,88	17.79	< .001
Gram * Region * Group	4,88	2.14	.083

Table 4.14: Global analyses of ERP data at midline electrodes (TW 700-1000)

A main effect of Grammaticality emerges. Again, the significant interaction with Region indicates that the component is differently distributed on the scalp. Paired t-tests performed to compare correct and incorrect conditions for each electrode revealed that the component was significant only at central and posterior electrodes (Fz, $t(47) = .02$, $p > .05$; Cz, $t(47) = -3.10$, $p < .005$; Pz, $t(47) = -3.88$, $p < .001$). In addition, at midline electrodes the interaction Grammaticality *

Region * Group also approached significance, showing a different localisation of the component in the groups. Separate ANOVAs for groups were then performed. In the control group, the main effect of Grammaticality approached significance, $F(1,15) = 3.762$, $p = .071$, and the interaction Grammaticality * Region reached it, $F(2,30) = 14.51$, $p < .001$. Paired t-tests revealed that the component was significant only at Pz, $t(15) = -3.53$, $p < .005$, and approached significance at Cz, $t(15) = -1.84$, $p < .086$. In the DD+SLI group, the main effect of Grammaticality approached significance, $F(1,15) = 3.20$, $p = .094$, and the interaction Grammaticality * Region reached it, $F(2,30) = 4.55$, $p < .05$, showing that the component was significant only at Cz, $t(15) = -2.63$, $p < .05$, and approached significance at Pz, $t(15) = -1.94$, $p = .071$. Differently, no main effect or interaction emerged in the DD-Only group, confirming the absence of this second component in this group.

4.5.3 Discussion

Dyslexic children with and without additional language impairment have been compared to control children in an electrophysiological experiment involving subject-verb agreement violations. Based on the wide literature on the ERP correlates of subject-verb agreement violations (see Section 2.3 for a systematic review), a classical bi-phasic pattern (LAN/P600) was expected for control participants. In contrast, anomalies in the typical ERP components were expected in both dyslexic groups, but more pronounced in the DD+SLI group, that was impaired also at the behavioural level (as described in Section 4.4).

In line with expectations, agreement violations evoked in the **control group** a non-robust LAN, between 250 and 550 ms, and a broad positive wave, interpretable as a P600, between 700 and 1000 ms. The fact that the LAN is only approaching significance in this sample of Italian children is not surprising. Previous studies have already shown that this ERP component is cross-linguistically less robust than other components (Balconi & Pozzoli, 2005; Hagoort et al., 1993; Rispens et al., 2006). In addition, also in our previous study (Chapter 3) the LAN was not robust in control adults.

Another noteworthy point concerns the relatively delayed latency of both the LAN and the P600 components (with respect to the literature based on adults). These latencies are however consistent with the literature on electrophysiological correlates of (morpho)syntactic processing in early development (see Section 2.4). Generally, typical-developing children older than 32 months show adult-like electrophysiological correlates of (morpho)syntactic processing (Atchley et al., 2006; Hahne et al., 2004; Oberecker et al., 2005; Silva-Pereyra et al., 2005; Silva Pereyra et al., 2005). Differences with respect to adults only concerns the latency and the duration of the components.

LAN and P600 are generally delayed in children, showing that the syntactic processing is less automatic than in adults (Hahne et al., 2004; Oberecker et al., 2005). Additionally the duration of the P600 has been sporadically found to be increased in children (Atchley et al., 2006), reflecting an additional effort. Although in the present study a direct comparison between adults and children is not possible, due to differences in the recording procedures, our results qualitatively confirm a delayed latency, as well as an increased duration and amplitudes, of the components typically found in adults.

Dyslexic children showed a different electrophysiological pattern, characterised by a Negativity broadly diffused all over the scalp that cannot be functionally interpreted as a LAN (reflecting the detection of the morphosyntactic error), but rather as an N400 component (usually associated with lexical-semantic processing). Interestingly, this result resembles our previous findings obtained using the same paradigm in a sample of Italian dyslexic adults (see chapter 3). As already argued, similar evidence of an N400-like component in response to morphosyntactic violations was previously found in studies conducted on language impaired populations, namely aphasic patients (Hagoort et al., 2003), children with (g-)SLI (Fontaneau & Van der Lely, 2008; Sabisch, 2007) and in adults learning a second (Chen et al., 2007; Osterhout et al., 2008; K. Weber & Lavric, 2008) or an artificial language (Morgan-Short et al., 2010; Steinhauer et al., 2009). In light of the recent literature, the N400 enhancement is interpreted as reflecting the retrieval of explicit rules or lexically stored forms, in an attempt to compensate for difficulties in constructing implicit rules for handling inflectional morphology (for a further discussion see Section 3.4.1).

Against expectations, **dyslexic children with additional SLI** showed an electrophysiological pattern more similar to their control peers. Statistical analyses revealed the presence of a non-robust N-400 like (similar to DD-Only children), significant only at midline electrodes, as well as the presence of a P600 component. The complete absence of the LAN reflects that the detection of the violation is not automatic. Additionally, the cognitive strategy apparently similar to that of controls, reflected in the P600 component, is not helpful at the behavioural level, given the results in the grammaticality judgement task.

As already reviewed (see Section 2.5.5), only limited research has been performed regarding electrophysiological correlates of (morpho)syntactic processing in children with SLI. To date, these ERP studies have clearly demonstrated that this population detects (morpho)syntactic anomalies differently than children with typically developing language (Betz, 2005; Fontaneau & Van der Lely, 2008; Oberecker, 2007; Sabisch, 2007; Sabisch et al., 2009). In particular, the anomalous detection of grammatical violations in the different studies has been expressed at the

electrophysiological level in different ways. Children at risk for SLI and younger SLI children showed a complete lack of the typical ERP components (LAN/P600), demonstrating a developmental delay in the syntactic processing abilities, not only with respect to initial on-line syntactic structure building, but also with respect to late processes of syntactic integration (Betz, 2005; Oberecker, 2007). Less consistently, older SLI children have been reported to show: delayed LAN (in term of latency), reflecting a less automatised process (Sabisch, 2007; Sabisch et al., 2009); presence of an N400-like instead of the expected ELAN, reflecting a sort of lexical-semantic compensation (Fontaneau & Van der Lely, 2008; Oberecker, 2007); increased P600, suggesting a heightened awareness of the syntactic errors (Betz, 2005).

In this wide panorama, the results of the present study are particularly unexpected. Similar to Sabisch's (2007) results, DD+SLI children lack the LAN, reflecting the absence of the automatic detection of the violation. However, in our case this finding is not particularly convincing, given the fact that the LAN component is not robust in the control sample, too. Additionally, at electrophysiological level our DD+SLI children differ from control children mainly because of a weaker P600 component. As this component is mainly interpreted as reflecting controlled process of reanalysis of the violation, the reduced robustness of the component in DD+SLI children suggests a less accurate analysis. As already discussed, this is reflected also in their behavioural performance in the grammaticality judgement task, where DD+SLI children performed significantly worse than control children.

However, the most interesting result of the study is the **direct comparison between dyslexic children with and without SLI**. In the literature, only a few studies have directly compared electrophysiological correlates of (morpho)syntactic processing in reading impaired children with and without language impairment. Sabisch (2007) used the same paradigm (phrase-structure violation) with DD and SLI children (although not matched for age), and found a similar anomalous pattern, although more compromised in SLI children (see Sections 2.5.4 and 2.5.5 for further details). In particular, both clinical groups lacked the early LAN shown in the control group. While DD children had a delayed LAN (300-600 ms), SLI children had an even more delayed component (700-1000). Other studies, mainly using paradigms concerning lexical-semantic processing, similarly reported that the electrophysiological anomalies shown by DD individuals were situated in an intermediate position between control and SLI participants (Helenius et al., 2009; Neville et al., 1993; Sabisch, 2007), thus demonstrating that "*SLI and dyslexia seem to form a continuum from a milder to a more severe expression of difficulties in terms of subtle defects of linguistic activation*" (Helenius et al., 2009, p. 9).

The results in the present study, however, point toward a qualitative difference between DD-Only and DD+SLI children in the processing of morphosyntactic violations. The difference might be in the use of cognitive strategies to resolve the violations. Our personal hypothesis is that DD-Only have found a lexical-semantic strategy to compensate the difficulty in handling inflectional morphology. Conversely, DD+SLI children do not possess this compensatory strategy. They should thus rely on the same cognitive strategy used by control children, that however is not efficient at the behavioural level. The fact that DD-Only and DD+SLI children functionally differ at this age (8 to 12 years old), however, does not mean that the groups are structurally different. It could be still hypothesised that DD and SLI disorder have a common origin, but that then some children develop only reading disorders, while other additionally present deficits in linguistic processing. Further investigations are needed in order to clarify this point, particularly it would be interesting to investigate children's skills before they developed the disorder and compensatory strategies. The study of younger children at risk for DD and SLI seem thus to be very important, also in order to identify possible protective factors, that mainly led to the development of adequate compensatory strategies.

A final remark concerns the role of metalinguistic skills in grammaticality judgement task (Lum & Bavin, 2007). Interestingly, in the ERP results DD+SLI children demonstrated to implicitly detect the morphosyntactic violations, while at the behavioural level they showed difficulties in correctly judging grammatical vs. ungrammatical sentences. It could be hypothesised that their problems are more related to metalinguistic skills. Further studies, however, need to be done in order to confirm this strong and complete speculative hypothesis.

4.6 General discussion

Based on the results obtained in the three experiments, and on the specific discussion provided at the end of each experiment, here is an attempt to answer to the experimental questions mentioned in the introduction.

- a) *Assuming that both DD-Only and DD+SLI children are characterised by phonological impairments, the question remains, are these deficits the same or different? And if the behaviours do differ, are the differences quantitative or qualitative?*

As expected, both dyslexic groups are characterised by a phonological impairment, concerning short-term and working memory, phonological processing and phonological awareness. The deficit

seems however more severe in DD+SLI children, whose performances are always different from those of control children, and for some tasks from those of DD-Only children, too. The difference seems to be qualitative instead than only quantitative. Different patterns of phonological performance has been found between the two dyslexic groups, concerning the tasks tapping phonemic awareness, and the non-word repetition task. In particular, phonological performances in DD-Only children seem to be more impaired when several skills are simultaneously involved (as in the Spoonerisms or in the Non-word repetition for longer non-words). The presence of different deficits underlying the two disorders has been thus hypothesised.

b) When using particularly sensitive measures, is it possible to determine whether DD is associated with a broader linguistic impairment, particularly concerning the morphosyntactic domain? Again, is the morphosyntactic impairment similar to that shown by DD+SLI children (only less severe) or are there qualitative differences between groups?

The experiments have unequivocally demonstrated that there are dyslexic children who next to their reading problems have difficulties with oral language. At the behavioural level, they have problems in inflectional morphology, and in particular in producing morphological manipulations of non words. At electrophysiological level, they show anomalies in the ERP correlates of subject-verb agreement violation, presumably due to the use of a qualitatively different strategy to process the violations. Based on both behavioural and electrophysiological data, a further comment on the cognitive strategy might be done. In the ERP experiment, the presence of an N400-like component suggests that the compensatory strategy might have a lexical-semantic nature. Similarly, concerning the behavioural tasks, DD-Only children failed when manipulations on non-words are required, and thus when a lexical-semantic compensatory strategy cannot be used. The consistent results deriving from different data seems to reinforce our hypothesis. Those dyslexic children apparently not impaired in oral language could have developed a compensatory strategy mainly based on lexical-semantic processing.

Interestingly, the difficulties characterising DD-Only children seem to be qualitatively different from those shown by DD+SLI children, too.

Both these results are particularly relevant within the debate concerning the linguistic nature of DD and its overlap with SLI. On the one hand, the existence of an indefinite border between the two disorders is confirmed, given the fact that anomalies in the morphosyntactic domain, typically impaired in SLI children, have been found in participants with DD. On the other hand, qualitatively

different processing strategies have been found in dyslexic children with and without SLI. These results, however, do not allow us to draw firm conclusions about the exact relationship between the two syndromes as hypothesised in the previous literature. Our data seem more consistent with recent observations pointing toward the presence of different cognitive deficits that could underlay the manifestations of DD and SLI as isolated or comorbid disorders (Pennington, 2006; Pennington & Bishop, 2009). In the framework of multifactor models of learning disabilities, the emergence of different subtypes within the disorders is predicted, each with different patterns of underlying cognitive deficits probably originating from distinct aetiologies. Applying the *multiple overlapping risk factor model* to our data, it could be hypothesised that the two subgroups of dyslexic children we analysed (DD-Only vs. DD+SLI) present different patterns of underlying cognitive deficits (Marshall et al., unpublished).

What still need to be clarified is whether the cognitive deficits originated from distinct aetiologies, or whether they originated from the same aetiology, but differed in the course of development due to protective factors that allowed DD-Only children to develop cognitive strategies to compensate the original deficit. As already mentioned, further investigations are needed in order to clarify this point. In particular, it seems interesting to investigate children's skills at younger ages, also in order to identify the possible protective factors, that mainly led to the development of adequate compensatory strategies.

c) In light of the results in the formal and experimental linguistic evaluation in DD-Only children, do we need new diagnostic tests able to detect more subtle linguistic difficulties in school-aged children?

It is clear, from the results, that some of the tests used in the clinical practice to assess linguistic skills in school-aged children are not sensitive enough to detect the subtle linguistic deficit characterising dyslexic children. Based on the present results, the creation and standardisation of more sensitive tests to assess linguistic skills in school-aged children should follow at least two criteria, the adherence to specific characteristics of Italian and the involvement of implicit morphosyntactic knowledge. This latter point could be addressed both by asking to induce the rule to be applied from examples, and by using morphological manipulation of non-words, thus preventing the compensation through semantic strategies.

Appendix 4A: Distribution of single scores in the dyslexic groups

In order to quantify the difficulties in the two dyslexic groups, the distribution of scores in the control group was taken as a reference. Given the wide age range, each dyslexic child was compared with his/her matched control. In particular, the difference between scores (d-scores, computed as dyslexic score minus control score) were computed, and the distribution of d-scores was analysed taking the SD in the control group as a cut-off of normal variation.

In the table below, I present the percentages of children in the DD-Only and DD+SLI that are between 1 and 2 SD below their matched control (- 1 SD < X < -2 SD column) and the percentages of children that are between 2 SD below their matched control (-2 SD column). In the last column (χ^2) I present the p-value of the comparison between the distribution of d-scores in the two dyslexic groups.

Task	DD-Only		DD+SLI		χ^2
	- 1 SD < X < -2 SD	< - 2 SD	- 1 SD < X < -2 SD	< - 2 SD	
Digit span forward	6,7%	40%	33,3%	26%	.187
Digit span backward	26,7 %	6,7%	26,7%	13,3%	.824
Monosyllabic non-word span	46,6%	6,7%	20%	33,3%	.116
Non-word repetition	6,7%	33,3%	20%	66,7%	.028
Syllabic manipulation	25%	31,3%	13,3%	26,7%	.608
Spoonerisms	21,42%	50%	36,36%	27,3%	.496
Phonemic synthesis	36,36%	27,3%	28,57%	42,9%	.723
Grammatical judgement: subject-verb agreement	43,75%	25%	12,5%	68,8%	.038
Grammatical judgement: choice of the auxiliary	12,5%	25%	25%	56%	.042

Chapter 5

Experiment 3:

Characterising the morphosyntactic deficit and its relationship to phonology in German dyslexic adults

5.1 Brief introduction and outline of the chapter

In the present dissertation I have already widely discussed two types of evidence concerning the vast amount of literature available on DD.

On the one hand, evidence for a phonological impairment in DD has been well documented (see Section 1.2.1). However, according to some researchers (e.g., Tallal, 1980), phonological impairment is not a primary deficit but the consequence of underlying acoustical processing deficits that concern lower-level processing stages (see Section 1.2.1.2). Several studies show that dyslexic individuals have difficulties in extracting discrete phonological representations from phonetic features embedded in speech signal (e.g., Manis et al., 1997; Serniclaes, Sprenger-Charolles, Carre, & Demonet, 2001). In addition to behavioural studies, several electrophysiological experiments using Mismatch Negativity (MMN) paradigms confirm the presence of a phonemic discrimination deficit in DD (see Section 2.5.1). The MMN, as a measure of the brain's ability to detect differences between frequent standard and rare deviant stimuli, has often shown attenuated responses in dyslexic individuals compared to controls, especially for stop consonant-vowel syllables (Hommet et al., 2009; Lachmann et al., 2005; Schulte-Körne et al., 1998, 2001; Sharma et al., 2006).

On the other hand, although other higher-level linguistic domains such as semantic, morphological and syntactic skills have only been sporadically investigated in DD, evidence for a deficit in these areas has been widely documented in previous sections of this dissertation. For example, the few behavioural and electrophysiological studies that have focused on semantic

processing in DD, mostly showed subtle specific impairments (Betjemann & Keenan, 2008; Jednorog et al., 2010; Russeler et al., 2007), that, however, could be tracked back to anomalous phonological processing (Bonte & Blomert, 2004; Helenius et al., 2002; Mody et al., 2008). Behavioural studies addressing morphosyntactic and syntactic skills in DD populations generally revealed subtle deficits particularly concerning comprehension and production of complex syntactic structures and inflectional morphology (see Section 1.2.2). In addition, electrophysiological studies have reported anomalous cortical responses in response to sentence components with specific grammatical functions (Breznitz & Leikin, 2000, 2001) and to (morpho)syntactic violations (Rispen et al., 2006; Russeler et al., 2007; Sabisch et al., 2006). In our previous studies presented in Chapter 3 and 4, we also found different ERP patterns in the dyslexic and control groups. In particular, we generally found an N400-like component in response to subject-verb agreement violations for both dyslexic adults and children. This finding has been suggested to reflect an attempt to compensate difficulties in constructing implicit rules for handling inflectional morphology. In particular, the compensatory strategies that have been discussed concern the reliance on storage or the need to exploit aspects of lexical-semantic predictability.

Thus, although deficits in several linguistic domains have been observed in DD, particularly concerning phonology and morphosyntax/syntax, what is still unclear is the relationship between the two linguistic domains. As reviewed in Section 1.3.1, and more generally in Section 1.2, a wide range of literature has investigated this relationship both in SLI and DD.

One of the main explanatory theories on SLI, the *Surface Hypothesis*, traces morphological difficulties in SLI children back to phonological problems. Leonard and colleagues (Leonard et al., 1997) have pointed out that SLI children's typical difficulties in the production and comprehension of some morphemes (e.g., consonant inflections or weak-syllable morphemes) could have their basis in the deficient acoustical processing of the input, particularly in the difficulty to perceive short and rapid sounds such as some verbal and nominal inflections (Leonard, 1998; Tallal & Piercy, 1973). Within a *connectionist approach*, it has been demonstrated that many of the morphological errors in dysphasic speech can be produced by distorting the phonological input, thus confirming that a reduced processing capacity leads to a differential degradation of the less salient (and more difficult) items (Hoeffner & McClelland, 1993). Using the same approach, Joanisse and Seidenberg (Joanisse & Seidenberg, 2003) developed a model trained on distorted phonological input (i.e., simulating a perceptual deficit) that exhibited marked difficulties in resolving bound anaphors but not in many other aspects of sentence comprehension. Thus, the model delivered results consistent with behavioural data related to syntactic deficits in SLI. The authors' conclusion

of a causal relationship between perceptual and grammatical deficits in SLI has then been extended to explain grammatical deficits in DD (Joanisse, 2004; Joanisse et al., 2000)

In addition to problems in processing the acoustic input, other phonological deficits have been proposed to cause syntactic problems in both SLI and DD. For example, Chiat (2001) proposed a comprehensive *mapping theory* suggesting that the impaired phonological processing in SLI leads to the disruption of mapping processes considered as a *sine qua non* of language acquisition. Finally, Shankweiler and Crain (1986) proposed the “*processing limitation hypothesis*” to explain language mechanisms in reading disorders, in which the Working Memory (WM) system plays a central role. Recently, the relationship between WM load, Short-Term Memory (STM, as assessed by non-word repetition) and (morpho)syntactic skills in DD has been further investigated (Jiménez et al., 2004; Rispens & Been, 2007; Robertson & Joanisse, 2010). Findings revealed that sentence processing difficulties and reduced sensitivity to subject-verb agreement in dyslexia can be explained as a result of phonological STM limitations.

As further evidence, the general link between reading performance, phonological processing, and syntactic processing has been confirmed by studies conducted on large samples of first-grade and third-grade typically developing children (Gottardo, Stanovich, & Siegel, 1996; Plaza & Cohen, 2003). In particular, these studies found a general relationship between reading difficulties and deficient syntactic awareness suggested to arise as consequences of deficits in phonological processing.

The present study aimed to further characterise both the phonological and the morphosyntactic processing deficit in DD, and in particular to answer the following general question:

Are the (morpho)syntactic deficits revealed in DD specific or based on an underlying phonological impairment?

We took advantages of the features characterising the German morphological system in order to test the effect of a distorted phonological input on dyslexics’ morphological errors, by using an ecological approach. German-speaking adults with DD and unimpaired controls listened to short German sentences consisting of a pronoun and a verb matching or not matching the pronoun in number and performed a grammaticality judgement task. To investigate the interaction between phonological/acoustical and morphosyntactic processing, the verbal inflections were manipulated to consist of three levels of acoustical salience (e.g., Low: *ich mache* vs. **ich machen*; Medium: *du kaufst* vs. **du kaufst*; High: *du nimmst* vs. **du nehmt*). This manipulation aimed at clarifying

whether the morphosyntactic processing difficulties in DD can be considered as a primary and independent deficit, or are due to underlying phonological deficits, in particular to the difficulty in perceiving short and rapid sounds, such as verbal and nominal inflections. If the second hypothesis is true, differences between the conditions are expected with respect to the ERP responses to the morphosyntactic violations. To further elucidate the relationship between morphosyntactic and phonological skills, we additionally collected ERP data on phoneme discrimination (/da/ vs. /ga/) and behavioural data on phonological processing and phonemic awareness from the same participants.

To our knowledge, the current study is the first to investigate morphosyntactic and phonological processing skills in the same sample of dyslexic participants by means of highly sensitive brain measures such as ERPs. Previous studies have investigated how phonological and semantic priming effects interact with each other (Helenius et al., 2002; Jednorog et al., 2010), and how difficulties in the semantic domain can be traced back to phoneme discrimination (Mody et al., 2008). Russeler and colleagues (2007) have considered phonological, semantic, and syntactic processing at the same time, however, without directly investigating the relationship between the different linguistic domains. In the present study, the direct manipulation of the acoustical salience of the morphemes marking number provides a direct measure of the relationship between different levels of language processing. In addition, the relationship between behavioural and electrophysiological measures of phonological and morphosyntactic skills will be further investigated through statistical correlations.

The present chapter has been structured in different sections. After a general methodological section, in which the characteristics of the sample are described, **Experiment 1** presents the behavioural and ERP results concerning phonological variables (i.e., short-term memory, phonological awareness, RAN) and **Experiment 2** presents the behavioural and ERP results concerning morphosyntactic processing. The presence of the single deficits will be discussed after each section, while the main question regarding the relationship between phonological and morphosyntactic deficits will be addressed in the general discussion.

5.2 General method

5.2.1 Participants

Thirteen young adults with DD (mean age 23.7 years, ranging between 20 and 30 years, 2 females) and 13 control participants were included in the study. All participants gave written informed consent prior to testing, and received 7 Euros per hour as compensation for their efforts. The study met the criteria requested by the Helsinki Declaration (1964). All participants were native speakers of German, and obtained intelligence scores within the normal range in a standardised intelligence test (nonverbal IQ > 85; *Advanced Progressive Matrices*; Raven, 1998). All of them had normal or corrected-to-normal vision and normal hearing, and additionally reported the absence of neurological or psychiatric disorders in a self-report questionnaire. All participants were right-handed as determined by the Edinburgh Inventory (Oldfield, 1971).

Participants with Developmental Dyslexia reported a history of difficulty with reading and spelling. Accordingly, they performed at the 10th percentile or lower (see Table 5.1) on a standardised test for reading speed and comprehension (*Lesegeschwindigkeits- und Verständnistest für die Klassen 6-12*; Schneider, Schlagmüller, & Ennemoser, 2007) and on a standardised spelling test (*Rechtschreibtest RT*; Kersting & Althoff, 2004). None of the dyslexic participants had a previous diagnosis of general or specific language impairment.

Control participants were selected to individually match each participant in the dyslexia group on age, gender and non-verbal IQ. Moreover, given that the dyslexic participants had different degrees of education (ranging from vocational school to university), the control participants were also selected on the basis of their graduation. All control participants reported never having experienced difficulty with reading or spelling. They scored within the normal range in a reading speed and comprehension test (*Lesegeschwindigkeits- und Verständnistest für die Klassen 6-12*; Schneider, Schlagmüller, & Ennemoser, 2007) and on a spelling test (*Rechtschreibtest RT* (Kersting & Althoff, 2004).

As summarised in Table 5.1, one-way ANOVAs revealed no significant differences between control and dyslexic participants on age and non-verbal IQ, while significant differences between groups were found with respect to both reading measures (for texts, words, and non-words) and spelling measures.

VARIABLES	Control participants Mean (SD)	Dyslexic participants Mean (SD)	One-way ANOVA (<i>p-value</i>)
N (Female)	13 (2)	13 (2)	
Age (years; months)	23.6 (3.2)	23.7 (2.8)	.900
Nonverbal intelligence	102.3 (10.11)	99.8 (13.09)	.585
Spelling (M = 100, SD = 10)	105 (7.11)	80.62 (4.71)	< .001
Text reading (M = 50, SD = 10)			
Speed	58.8 (10.56)	45.1 (7.47)	.001
Comprehension	63.7 (9.49)	51.2 (8.17)	.001
Word reading (N=12)			
Speed (sec)	39.52 (8.35)	48.58 (12.85)	.05
Errors	0.5 (0.67)	2.15 (2.23)	< .05
Nonword reading (N=12)			
Speed (sec)	69.04 (12.21)	108.12 (26.78)	< .001
Errors	1.75 (1.65)	11.69 (6.57)	< .001

Table 5.1. Participants characteristics

5.2.2 Diagnostic and standardised tests for reading and spelling skills

Reading and spelling skills were assessed by different tasks:

- Silent text reading was assessed by the *Lesegeschwindigkeits- und Verständnistest für die Klassen 6-12* (Schneider et al., 2007), providing speed and comprehension scores. Participants have 4 minutes of time to read as much as possible of a text, and to fill in missing gaps in the text using one of three possible options. Norms for speed and comprehension scores are available for young teenagers aged between 12 to 18 years.
- Word and non-word reading was assessed by a standardised test (Schulte-Körne, 2001) requiring participants to read out loud a list of 48 words and a list of 48 pronounceable non-words as accurately and quickly as possible. Separate raw scores were computed for speed (seconds necessary to read the whole list) and accuracy (number of mistakes).
- Spelling was assessed by the *Rechtschreibtest RT* (Kersting & Althoff, 2004), in which participants were asked to fill in missing words of a text (mainly irregular German words), which the tester read out loud. Scores are expressed as standard scores (M = 100, SD = 10), referring to German norms for high school students.

5.2.3 General testing procedure

All participants attended four test sessions at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig. The first session was arranged as a group test session. It lasted around 1.5 hours and involved behavioural assessment of nonverbal intelligence, spelling, reading speed, and reading comprehension. The other sessions were designed as individual sessions. The second session lasted about one hour and focused on the behavioural assessment of phonological skills. The third session lasted around 2 hours and comprised the agreement violation ERP experiment. The fourth session lasted around 2 hours and involved the MMN experiment and the behavioural agreement violation experiment. All participants attended the first three sessions, while one control participant (female) could not attend the fourth session, so that her matched control was deleted from the sample for the last experimental results, in order to keep the groups perfectly matched.

5.3 Experiment 1: Behavioural and electrophysiological characterisation in phonological skills

5.3.1 Behavioural assessment

Verbal short-term memory and working memory

- Digit span: The “forward” and “backward” digit span tasks of the German version (HAWIE-R) of the *Wechsler Adult Intelligence Scale* (Tewes, 1991) were used. The standard scores (M= 10, SD = 5) were computed, summing scores in the two subtests and referring to age norms.
- Non-word repetition: A subtest of a standardised battery for dyslexia assessment (Harbodt, Sabisch, Cantiani, & Barry, in preparation) was used. The test consisted of 19 nonsense words, ranging in length from two to five syllables, and conforming to the phonotactic constraints of German. The accuracy score was computed as the number of correctly repeated syllables (maximum score 64).
- Sentence repetition: Another subtest of the same standardised battery for dyslexia assessment (Harbodt et al., in preparation) was used in order to assess verbal short-term memory in a linguistic context. Twelve sentences ranging in length from eight to twenty-two words and involving different syntactic structures were auditorily presented. An accuracy score was computed (maximum score 26).

Phonological awareness

A spoonerism task taken from the same standardised battery for dyslexia assessment (Harbodt et al., in preparation) was used to assess phonological awareness at phoneme level. The task requires to interchange the initial phonemes of the auditorily presented first name and surname of 12 well-known German people or television characters (e.g., *Biene Maja* to *Miene Baja*). The accuracy score was computed with respect to correct phoneme replacements, correct rhymes, and correct order for each item (maximum score 60). Response time was measured from the offset of the stimulus to the offset of the response.

Rapid Automatic Naming (RAN)

Lexical access and retrieval of phonological representations were assessed using the Rapid Automatic Naming (RAN) task (Denckla & Rudel, 1974) with four separate stimulus sets, i.e., digits, letters, objects, and colors. The overall time taken to read through each sheet and the total number of mistakes (involving omission, substitution, and auto-correction) were recorded.

5.3.2 Electrophysiological assessment of phoneme discrimination

Phoneme discrimination was assessed in a Mismatch Negativity (MMN) experiment. Stimuli were presented by a PC-based stimulus delivery system (ERTS) in an oddball paradigm.

5.3.2.1 Stimuli and experimental procedure

The auditory stimulation sequences consisted of naturally produced consonant-vowel syllables (/da/ and /ga/), spoken in isolation by a male 35-year-old native speaker of standard German. After recording and digitisation (44.1 kHz, 16 bit sampling rate) the vowel ending from another sample was mounted on each consonant (starting 35 ms after syllable onset) to guarantee that the phonemes only differ in their first transient.

The stimuli were presented in two blocks, each lasting 6 min. In each block, 120 deviant stimuli (probability of occurrence 12,5%) and 840 standard stimuli (probability of occurrence 87,5%) were presented. In one block, the deviant stimulus was /da/, while /ga/ served as standard stimulus, and vice versa in the other block. The order of the two blocks was counterbalanced between participants. Within blocks, stimuli were presented in a pseudo-randomised order so that there were at least 3 standards between 2 deviants. Each auditory stimulus was of 150 ms duration and the Stimulus Onset Asynchrony (SOA) was 800 ms for all stimulus sequences (Inter-Stimuli Interval

[ISI] = 650 ms). The MMN was derived by subtracting the standard waveform from the deviant waveform. The stimuli were presented binaurally through headphones with an intensity of 70 dB. During the recording session, participants were seated in a comfortable chair in a quiet room. They were instructed to ignore the presented stimuli while watching a self-chosen silent movie without subtitles.

5.3.2.2 EEG data acquisition

EEG data were recorded from 23 Ag/AgCl electrodes placed according to the international 10-10 system (Chatrian, Lettich, & Nelson, 1988) at the following positions: FP1/2, F7/8, F3/4, Fz, FC5/6, T7/8, C3/4, Cz, CP5/6, P7/8, P3/4, Pz, O1/2. Blinks and vertical eyes movements (VEOG) were monitored using two electrodes that were placed above and below the right eye. Horizontal eye movements (HEOG) were recorded from two electrodes located at the outer left and right canthi of the eyes. Additionally, one electrode was placed on the sternum and served as ground electrode, while two electrodes were placed on the right and left mastoids, with the latter as online reference.. All electrode impedances were kept below 5 k Ω . All electrodes were connected to an Xrefa amplifier (Twente Medical systems, The Netherlands). EEG signal was digitalised at the rate of 250 Hz and online bandpass filtered (0.01-70 Hz).

After recording, the EEG signal was re-referenced offline to the average of the right and left mastoids and bandpass filtered at 0.1-20 Hz. The continuous EEG signal was then exposed to an automatic rejection criterion applied to all electrodes, i.e., sections exceeding a SD of 40 μ V within a sliding time window of 200 ms were excluded. Afterwards, the trials with typical eye movements were identified through manual inspection and corrected using an EOG correction tool implemented in EEP software (EEP software, MPI, Leipzig, Germany). All ERPs were time-locked to the onset of the syllables.

ERPs were calculated with respect to a pre-stimulus baseline of 100 ms for an epoch of 650 ms. The factors Hemisphere and Region were crossed, yielding in six Regions of Interest (ROIs), with three electrodes each: Left Anterior (F7, F3 and FC5), Right Anterior (F4, F8 and FC6), Left central (T7, C3 and CP5), Right Central (C4, T8, CP6), Left Posterior (P7, P3 and O1), and Right Anterior (P4, P8 and O2). Separate analyses were performed for the three midline electrodes (Fz, Cz and Pz).

5.3.3 Results

5.3.3.1 Behavioural results

The results of the behavioural phonological tasks were analysed by one-way ANOVAs, and are reported in Table 5.2. Dyslexic participants show significantly lower performance compared to control participants in all tasks except for the Sentence Repetition task (involving syntactic skills beyond verbal memory) and the RAN task (although the time score difference between groups approaches statistical significance).

VARIABLES	Control participants Mean (SD)	Dyslexic participants Mean (SD)	One-way ANOVA (<i>p</i> -value)
Spoonerisms			
Accuracy (max. 60)	59.54 (1.127)	56.77 (3.059)	.005
Response time (sec.)	2.49 (0.6)	6.089 (3.038)	< .001
Digit span (M=10, SD=5)	12.54 (3.688)	9 (1.732)	.005
Nonword repetition (max. 64)	60.00 (2.273)	55.23 (5.357)	< .01
Sentence repetition (max. 26)	18.54 (2.436)	17.23 (3.492)	.279
Rapid naming (RAN)			
Time (sec.)	87.84 (13.304)	97.119 (11.794)	.072
Errors	2.923 (4.923)	3.692 (3.923)	.664

Table 5.2: Phonological behavioural tasks: Results for control and dyslexic participants

5.3.3.2 ERP results

The ERP data for the MMN experiment are displayed in Figure 5.1. Due to technical problems, a control participant and his matched dyslexic participant were excluded from the analyses, thus resulting in N = 11 for both groups. ERP data were collapsed for standards and deviants across /da/ and /ga/, as no differences were expected between the two syllables.

After careful visual inspection of the average ERPs across all subjects, the Time Window (TW) 120-230 ms was selected for statistical analyses on mean amplitudes. In this TW, the MMN for each ROI was derived by subtracting the standard waveform from the deviant waveform. For the lateral electrodes, a repeated measures ANOVA was performed with the between-subject factor Group (dyslexics vs. controls) and two within-subject factors, namely Hemisphere (left vs. right) and Region (anterior vs. central vs. posterior). For the midline electrodes (Fz, Cz, Pz), the same analysis was performed, with Group as between-subject factor and Region as within-subject factor.

At lateral electrodes, results revealed a significant main effect of Group ($F(1,20) = 3.053$; $p < .05$

(1-tailed), driven by more pronounced MMN amplitudes in the control group ($M = -1.12$; $SD = .039$) than in the dyslexic group ($M = -.085$; $SD = .034$). Despite the main effect of Region ($F(2,40) = 9.258$; $p < .001$), paired t-tests showed that the difference between standard and deviant waveforms reached significance in each region, but was more pronounced at central electrodes (Anterior electrodes: $t(21) = 9.44$; Central electrodes: $t(21) = 10.80$; Posterior electrodes: $t(21) = 8.52$; all $p_s < .001$). The absence of two-way and three-way interactions involving Group suggests a similar localisation and lateralisation of the MMN in both groups. At midline electrodes, no main effect of Group emerged ($F(1,20) = 1.334$; $p > .05$), probably due to a problem of statistical power (given both the few electrodes involved, and the few participants tested).

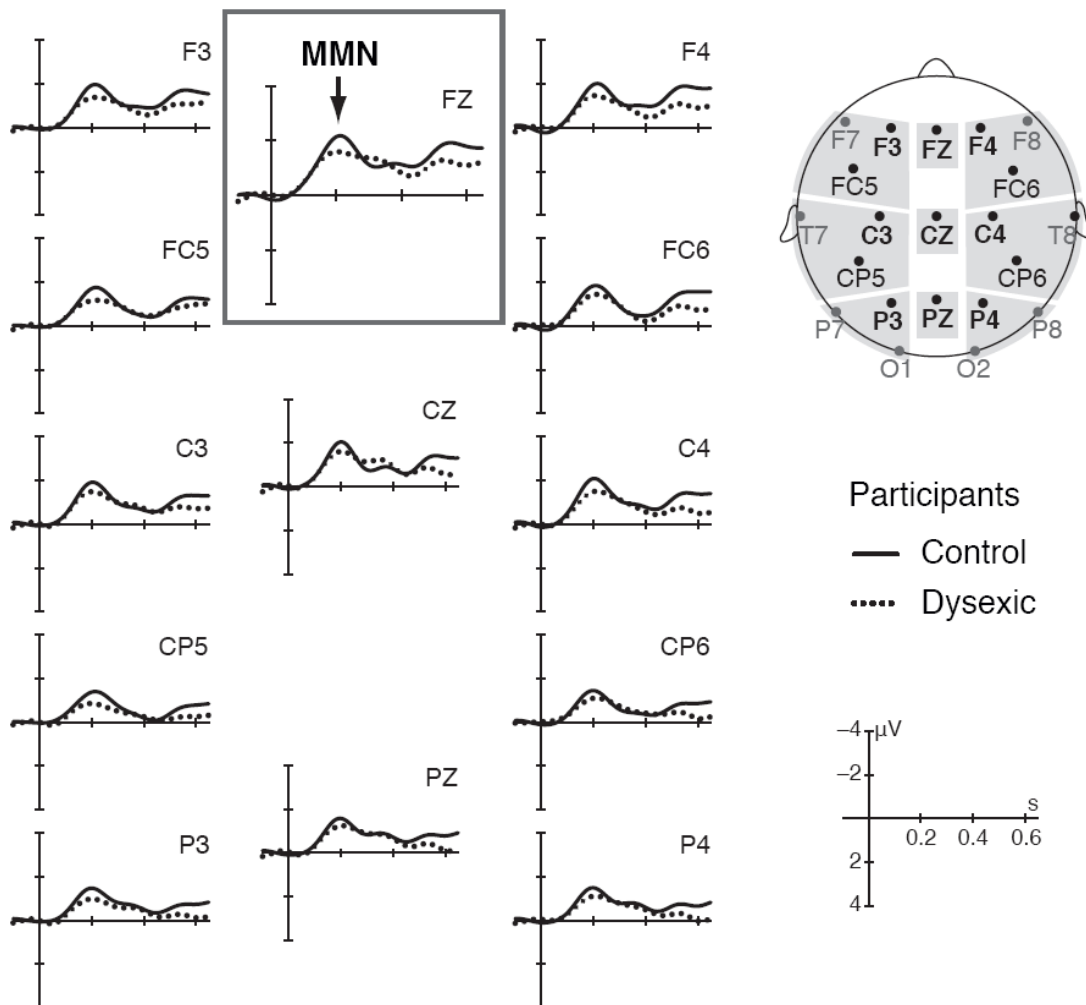


Figure 5.1: Grand average ERPs for the MMN experiment. Subtraction waves obtained by subtracting the ERP to the standards from the ERP to the deviant are presented for both control participants (continuous line) and dyslexic participant (dot line). Negative voltage is plotted upward. The plot has been filtered with a 7-Hz low-pass filter for presentation purpose only

5.3.3.3 Correlations between phonological measures

Pearson correlations between different measures of phonological processing were calculated. As presented in Table 5.3, all behavioural measures correlate with each other, except for sentence repetition and RAN (errors and time)²².

Unexpectedly, the ERP measure of phoneme discrimination, computed as the mean amplitude of the MMN in each ROI, only correlates with RTs in the RAN task, reflecting that slower responding participants in rapid naming showed lower levels of phonemic discrimination.

	MMN: mean ampl.	NW read. errors	Digit span	Spoon. acc.	Spoon. RT	NW repet.	Sent. repet.	RAN: Errors
NW read. err.	.119	1						
Digit span	-.122	-.498*	1					
Spoon. acc.	-.151	-.681***	.430*	1				
Spoon. RT	.117	.644**	-.578**	-.764***	1			
NW repetition	-.187	-.563**	.451*	.713***	-.747***	1		
Sent. repetition	-.217	-.263	.309	.603**	-.507**	.598**	1	
RAN: Errors	.138	.231	.038	.013	-.063	-.140	.087	1
RAN: RT	.449*	.076	-.460*	.026	.145	-.019	-.169	-.139

* < .05 ** < .01 *** < .001

Table 5.3. Pearson correlations between phonological measures

5.3.4 Discussion

As expected, different aspects of phonological processing were shown to be impaired in DD (i.e., phonological awareness, verbal short-term memory and phonemic discrimination). This finding is not surprising, given the number of studies showing impaired phonological processing even in well-compensated dyslexic adults (for example, see Bruck, 1992; Ramus et al., 2003 for deficits in verbal-short-term memory and phonological awareness in DD adults). Phonemic discrimination is a more controversial domain, as the few previous studies investigating MMN in dyslexic adults have found contrasting results (see Section 2.5.1 for an extensive review). In particular, clear differences in the amplitude of the MMN between control and dyslexic adults have been found only by Hommet et al. (2009). In contrast, Schulte-Körne et al. (2001) only found differences in the amplitude of a later component (LMN) and Sebastian & Yasin (2008) failed to find any differences

²² Interestingly, when performing Pearson correlations for each group, these correlations were still significant only in the DD group.

between dyslexic and control adults.

Differences between dyslexic and control participants failed to reach statistical significance only in the Sentence repetition task and in the RAN task. As already pointed out, repeating sentences does not only involve verbal short-term memory. Syntactic skills, as well as lexical-semantic skills, are also involved. The dyslexics' performance, comparable to that of controls, can be interpreted as the confirmation that the dyslexic adults in our sample were not formally impaired in syntactic and lexical-semantic skills. Moreover, the storage and retrieve of long sentences might be helped by meaningful verbal information. Thus, while a deficit in short-term memory emerged in the non-word repetition task, it seemed to be compensated in the sentence repetition task, probably thanks to the use of "top-down" knowledge to store and retrieve sentences.

The absence of significant impairments in the RAN task reflects a normal lexical access in the present sample of German dyslexic adults. It stands in contrast with previous findings that RAN is more important than phonemic awareness in predicting reading in transparent orthographies, such as German (Wimmer, Mayringer, & Landerl, 2000), Italian and Scandinavian (Di Filippo et al., 2006; Furnes & Samuelsson, 2010), and is more in line with recent findings that RAN is only a weak component irrespectively of language orthography (Ziegler et al., 2010)²³.

Additionally, the pattern of correlations between phonological skills, showing strong a relationship between all phonological variables except for the RAN, further confirms the existence of a dissociation between phonological processing skills and RAN (Wolf & Bowers, 1999). Unexpectedly, the electrophysiological measure of phoneme discrimination (MMN) is also weakly related with other phonological skills. It only correlates with the time measure of the RAN task. This counterintuitive result needs further investigation before being discussed, particularly in light of the reported difficulty in getting correlations between behavioural and MMN measures, often characterised by poor reliability at individual level or poor test-retest reliability (see Barry et al., 2008 for a further discussion on lack of such correlations). Moreover, it should be remembered that a note of caution is warranted, given the small number of participants in each group (N ranging from 11 to 13) and the high number of correlations computed.

²³ However, it should be noted that all the studies I have reported here have been conducted on children (up to Grade 5). Our results obtained for adults (mostly university students) are thus not directly comparable.

5.4 Experiment 2: Behavioural and electrophysiological characterisation in morphosyntactic skills

5.4.1 Assessment

Morphosyntactic processing was assessed by an experiment on subject-verb agreement violations, providing both behavioural and an ERP data, and in which the acoustical salience of the verbal inflections was manipulated.

5.4.1.1 Stimuli

Two-word utterances that were either correct or involved subject-verb agreement violations were created. German offers different ways to mark person. Within the regular system, including so-called weak verbs, verbal morphemes are generally consonant inflections, i.e., *-st* for the 2nd singular person (e.g., *du mach-st*), *-t* for the 3rd singular person (e.g., *er mach-t*) and the 2nd plural person (e.g., *ihr mach-t*), or syllabic reduced inflections (ρ°) produced by a consonant plus a schwa ($/\partial/$) in the 1st singular person (e.g., *ich mach-e*) and by a consonant plus a syllabic consonant ($/n/$) in the 1st plural person (e.g., *wir mach-en*) and the 3rd plural person (e.g., *sie mach-en*). In contrast, within the irregular system, including so-called strong verbs, the 2nd and 3rd singular persons are formed by changing the radical vowel, in addition to the typical suffix (e.g., *fahren (to drive): fahre - fährst - fährt*). In other words, in strong verbs, there are two different cues marking person, namely the consonant ending and the preceding vowel change in the verb stem. Taking advantage of these German subject verb-agreement rules, three different conditions testing the impact of acoustical salience were created (see Figure 5.2).

According to the acoustical salience of the respective verbal inflections, regular (weak) verbs were assigned to the Low or the Medium condition, while irregular (strong) verbs were assigned to the High condition (for a complete list, see Appendix 5A). The difference between the Low and Medium condition was created by manipulating the persons involved. In the Low condition, the 1st singular person and the 1st plural person were used, with the change concerning the substitution in the final phoneme $/-\partial/$ vs $/-n/$. In the Medium condition, the 2nd singular person and the 2nd plural person were involved, with the change concerning the presence or absence of the consonant $/s/$ preceding the inflection $-t$. The additional $/s/$ in the Medium condition was supposed to be acoustically more salient than the substitution in the final phoneme in the Low condition. In the High condition, the additional vowel change provides a second cue, which was supposed to make

the change in number even more acoustically salient than the one in the Medium condition. The successful step-wise manipulation of acoustical salience resulting in three differently difficult processing conditions were confirmed in two pilot experiments (see Section 5.4.1.2). As can be seen from Figure 5.2, for each verb, a correct and an incorrect version was created with the latter containing subject-verb agreement violations with respect to number.

ACOUSTICAL SALIENCE	Correct		Incorrect	
	Singular subject	Plural subject	Singular subject	Plural subject
LOW	ICH MACHE	WIR MACHEN	* ICH MACHEN	* WIR MACHE
MEDIUM	DU KAUFST	IHR KAUFST	* DU KAUFST	* IHR KAUFST
HIGH	DU HILFST	IHR HELFT	* DU HELFT	* IHR HILFST

Figure 5.2: Experimental design for the morphosyntactic experiment

All selected verbs were bisyllabic in the infinitive form, although they could be monosyllabic or bisyllabic in the inflected form. The transitiveness of verbs was verified by the online dictionary “Wortschatz” (www.wortschatz.uni-leipzig.de). Twenty-four transitive and eight intransitive verbs were included in each condition. The frequency was determined for each verb in the infinitive with the online dictionary “canoo.net” (www.canoo.net) and a univariate ANOVA revealed no frequency differences between verbs of the three salience conditions ($F(2,95) = 0.159$; $p > .05$).

The word pairs were spoken by a trained female native speaker of German and digitally recorded at a sampling rate of 44.1 kHz (16 bit; mono). The speaker was instructed to produce the word pairs with natural sentence prosody and to insert short pauses between words. Importantly, only correct word pairs were recorded. For both the correct and the incorrect versions, verbs were then spliced to the according pronoun, resulting in two correct and two incorrect word pairs per verb. All stimuli were normalised to 75 dB and pauses between pronoun and verb were adjusted to 120 ms. The signals were cut at zero crossing only. All manipulations were performed using the Praat software (www.praat.org). Previous studies have revealed that in the auditory domain the physical properties of language stimuli (acoustical differences in pitch, intensity, or length) can affect the early language-related ERP effects (Pulvermüller & Shtyrov, 2003). In order to test for differences between singular and plural stems, univariate ANOVAs were performed within the three salience conditions. No differences were found for pitch, intensity and duration in the Low and the Medium conditions (all $p_s > .05$), while a difference approaching statistical significance was found concerning pitch in the High condition, $F(1,127) = 2.93$; $p = .089$, for which differences in the verbal stems were expected due to the vowel change.

5.4.1.2 Pilot experiments

The manipulation of the acoustical salience of the verbal inflections, resulting in different levels of difficulty in the acoustical perception, was verified in two pilot experiments. The first experiment (EXP1) included 16 German-native-speakers (aged 21 to 31 years, $M = 24.56$, $SD = 2.8$) and the second experiment (EXP2) included 16 German-native-speakers (aged 21 to 27 years, $M = 23.87$, $SD = 1.78$). Based on our experimental hypothesis, we expected the violations in the Low condition to be the most difficult to perceive, while violations in the High condition should be the easiest to perceive. To make the task more demanding, and thus even suitable for non-impaired students, all stimuli were additionally embedded in white noises (performed in MATLAB; Math Works, Natick, MA), resulting in a signal-to-noise ratio of $SNR = 0$ in EXP 1 and $SNR = -6$ in EXP 2.

Participants listened to the stimuli in the natural and noised version in random order, resulting in a total of 768 items, and were asked to judge as fast as possible the grammaticality of the word pairs. Stimuli were presented by the Presentation software package (www.neurobs.com, version 13.0) through Sennheiser headphones (HD202) at a fixed intensity of 75 dB. Accuracy and Reaction Times (RTs) time-locked to the onset of the verbs were recorded.

Results are displayed in Figure 5.3. Concerning the accuracy, in both pilot experiments both Salience and Noise had an effect on the participants' grammaticality judgements (EXP1: Salience: $F(2,30) = 3.503$; $p < .05$; Noise: $F(1,15) = 60.982$; $p < .001$; Salience * Noise: $F(2,30) = 11.984$; $p < .005$; EXP 2: Salience: $F(2,30) = 77.652$; $p < .001$; Noise: $F(1,15) = 156.61$; $p < .001$; Salience*Noise: $F(2,30) = 105.63$; $p < .001$). As the graphs suggest, in both experiments violations in the Low condition were the most difficult to perceive in the noise condition. Paired t-tests performed on accuracy in the noise condition showed a difference between the Low condition and both the Medium and the High conditions (all p_s for both experiments $< .05$), while no difference has been found between the Medium and the High condition.

Concerning RTs, Noise revealed an effect in both pilot experiments, while Salience revealed a less consistent effect (EXP1: Salience: $F(2,30) = 3.654$; $p < .05$; Noise: $F(1,15) = 37.586$; $p < .001$; Salience * Noise: $F(2,30) < 1$; EXP 2: Salience: $F(2,30) = 1.795$; $p > .18$; Noise: $F(1,15) = 66.093$; $p < .001$; Salience*Noise: $F(2,30) = 3.347$; $p < .05$). Paired t-tests showed statistically significant differences between the Medium and the High condition, in EXP 1 for both the natural ($p < .01$) and the noise stimuli ($p < .001$), and in EXP 2 only for the natural stimuli ($p < .001$).

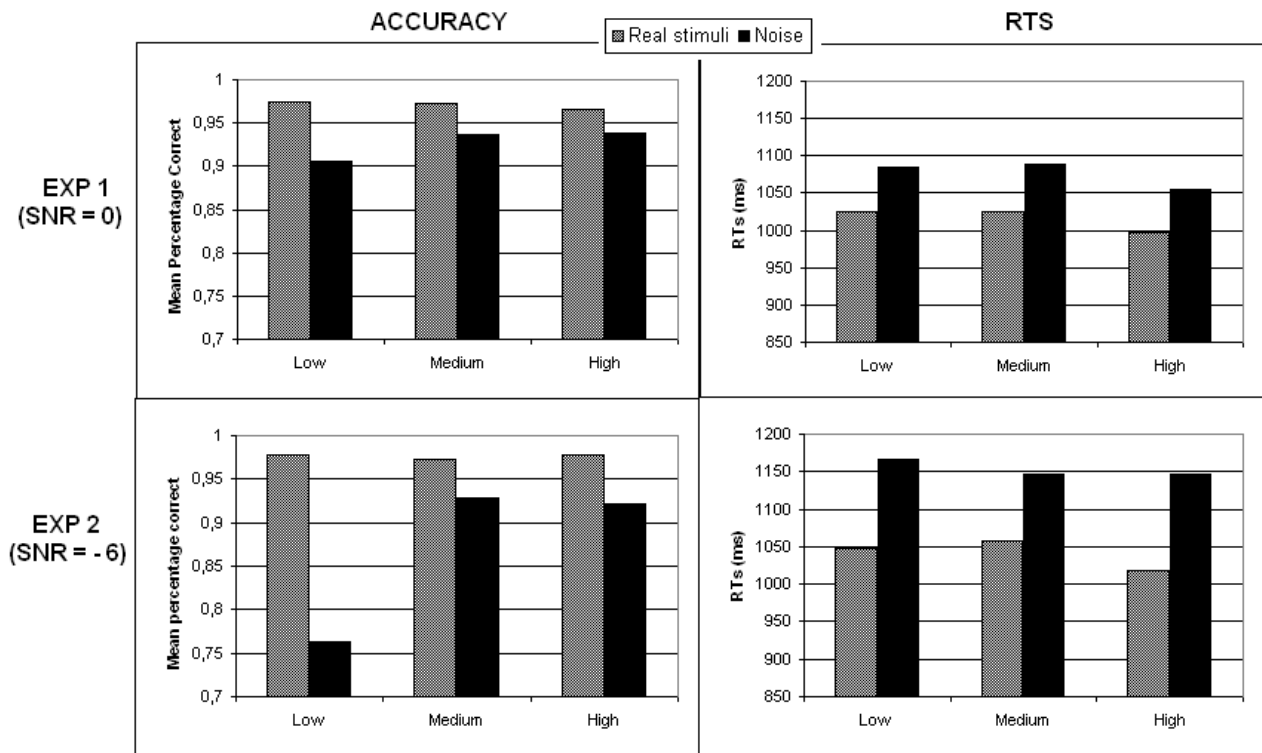


Figure 5.3: Results of the two pilot experiments

These results are in line with our hypotheses concerning the processing impact of the acoustical manipulation of the verbal inflections. While results regarding the accuracy of the grammaticality judgement confirm that violations in the Low condition are the most difficult to perceive, RT results confirm that violations in the High condition are easier to perceive than in the Medium condition, particularly suggesting that the vowel change is used as an additional cue to judge the syntactic agreement.

5.4.1.3 Experimental procedure

For the ERP experiment, a particular paradigm introduced by Hasting and Kotz (2008) was used, in which ERP responses to two-word utterances involving subject-verb agreement violations are compared to ERP responses to correct subject-verb pairs. This paradigm is related to both the syntactic-MMN paradigm (Hasting, Kotz, & Friederici, 2007; Pulvermüller & Shtyrov, 2003; Shtyrov & Pulvermüller, 2002) and the classical agreement violation paradigm (Hagoort & Brown, 2000; Osterhout & Mobley, 1995) and combines the advantages of both: In comparison to the agreement violation paradigm, Hasting and Kotz's (2008) results show that the sentence context is not necessary in order to evoke the typical ERP pattern associated with agreement violations, i.e., E-LAN and P600. In contrast to the syntactic-MMN paradigm, the new paradigm allows high

stimulus variability (i.e., a non-repetitive task) and in addition allows to perform a grammaticality judgement task. Furthermore, this particular procedure enables a precise time-locking of the ERP to the event of interest, i.e., the syntactic violation.

After the piloting, three verbs (one for each condition) were excluded due to very low accuracy (stimuli marked with * in Appendix 5A). The resulting 372 items of the natural version were arranged in two pseudo-randomised lists, so that no more than three items of the same syntactic properties (correct vs. incorrect), salience (Low vs. Medium vs. High) and number (singular vs. plural) were presented in a row. Four blocks were created, each containing 93 items, with the same number of items per salience condition in each block. Lists and blocks were counterbalanced across participants to avoid order effects. The stimuli were presented using the Presentation software package (www.neurobs.com, version 13.0).

Figure 5.4 shows one exemplary trial. Participants were instructed to fixate the star on the screen, to listen to the presented utterance, and to judge by button press whether it was grammatically correct or incorrect in a delayed response situation (1500 ms pause between stimulus presentation and response). The assignments of the two buttons for correct and incorrect judgements was counterbalanced across participants. The ERP experiment lasted approximately 45 minutes. For the duration of the experiment, the participants were seated in a comfortable chair positioned inside an acoustically and electrically shielded chamber, while an EEG was recorded. The two-word utterances were presented auditorily via loudspeakers at 75 dB.

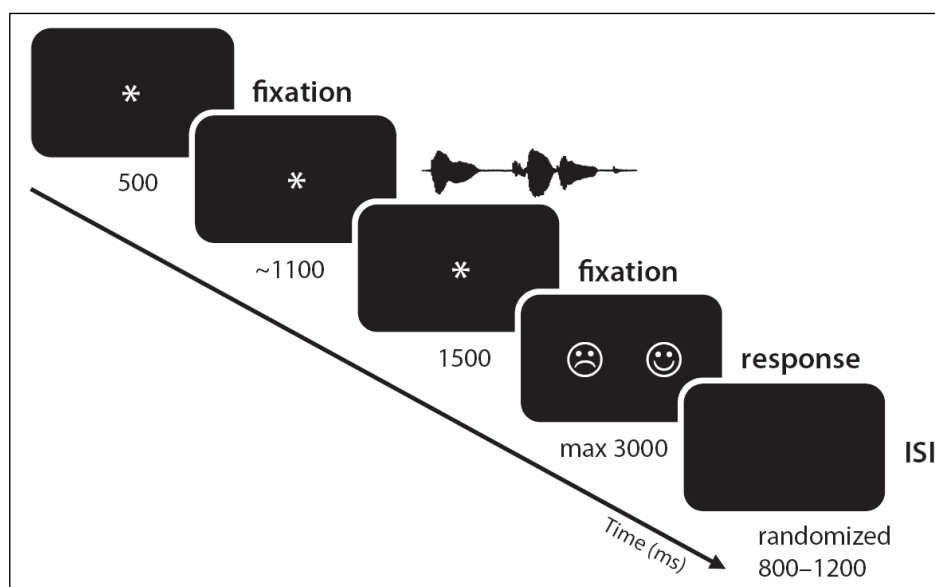


Figure 5.4: Sequence of events per trial in the ERP experiment on Morphosyntactic processing, including timing, visual and auditory input, and task requirements.

5.4.1.4 EEG data acquisition

The same EEG data acquisition procedure used for the MMN experiment (described in Section 5.3.2.2) was applied. Due to the specificity of the agreement violation experiment, ERPs were time-locked to either the onset of the verbs or the onset of the suffix. Moreover, ERPs were calculated with respect to a pre-stimulus baseline of 100 ms for an epoch of 1500 ms. Only trials with correct responses were included in the analyses.

5.4.1.5 Behavioural agreement violation experiment

The experiment was repeated in an additional session (approx. one month after the first session) in order to collect behavioural data on morphosyntactic processing. Here, participants were asked to judge as fast and correctly as possible the grammaticality of the word-pairs, while accuracy and RTs with respect to the onset of the verb were recorded. The procedure was identical to that used in the ERP experiment, with the only difference concerning the absence of a delayed answer, since participants were asked to respond immediately.

5.4.2 Results

5.4.2.1 Behavioural agreement violation experiment

Due to technical problems, a control participant and his matched dyslexic participant were excluded from these analyses, thus resulting in $N = 11$ for both groups. Separate repeated measures ANOVAs were performed for accuracy and RTs with Salience (High vs. Medium vs. Low) as within-subject factor and Group (controls vs. dyslexics) as between-subject factor. All participants performed above chance level in the grammaticality judgement task. The ANOVA performed for accuracy scores yielded no main effects or interaction effects (all $p_s > .05$), while the ANOVA performed for RTs (see Figure 5.5) yielded a main effect of Group ($F(1,20) = 9.110$; $p < .01$), driven by slower responses in the dyslexic participants ($M = 1050.768$ ms; $SD = 146.46$) compared to control participants ($M = 882.641$ ms; $SD = 112.60$). Additionally, a significant main effect of Salience emerged ($F(2,40) = 13.085$; $p < .001$). Paired t-tests showed faster responses in judging the word pairs in the High condition ($M = 942.628$ ms; $SD = 163.72$) with respect to both the Medium ($M = 975.112$ ms; $SD = 150.36$) and the Low ($M = 982.734$ ms; $SD = 151.79$) conditions ($t(21) = -5.01$; $p < .001$ and $t(21) = -4.14$; $p < .001$, respectively). No significant interaction emerged between Salience and Group, suggesting that the salience manipulation has the same affect on RTs in both groups.

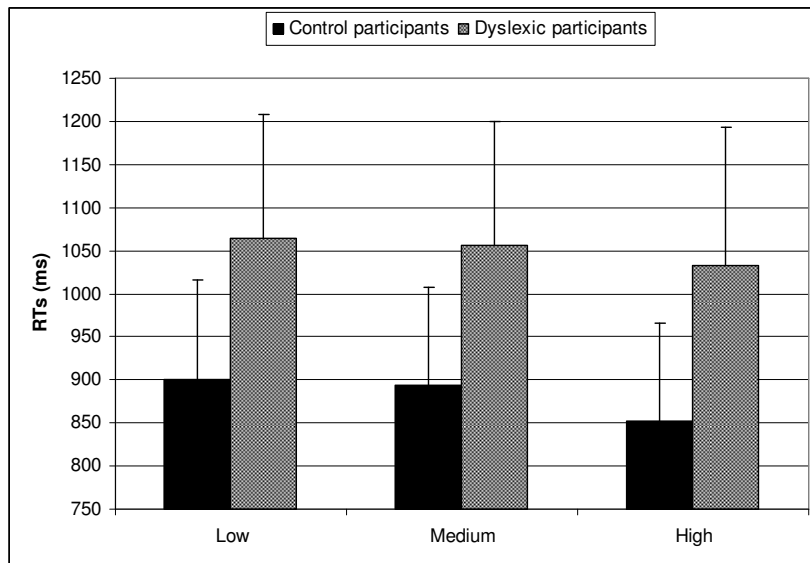


Figure 5.5: Behavioural agreement violation experiment: RTs expressed in ms

5.4.2.2 ERP results

As described in the method Section (5.4.1.1), experimental conditions of different acoustical salience of the inflections differed in the number of cues marking for person. While changes in the consonant endings were the only cue in the Low and the Medium condition, an additional vowel change in the verb stem characterised the High condition. Due to these differences, differently time-locked ERPs were considered for the three conditions. For the Low and Medium conditions, ERPs were time-locked to the onset of the suffix, while for the High condition ERPs were time-locked to the onset of the verb. Given these differences, separate sets of analyses were performed. First, analyses concerning the Low and the Medium conditions will be described, and second, analyses concerning the High condition will be presented.

5.4.2.2.1 Low and medium condition

As can be seen from Figure 5.6, two main ERP components emerged in response to morphosyntactic violations, a broadly distributed Negativity followed by a posteriorly distributed Positivity.

Statistical analyses were thus performed on two different TWs, selected on the basis of careful visual inspection of the ERP data. For the Negativity, the TW 100-400 ms was selected, while for the Positivity, the TW 500-1000 ms was chosen. Separate repeated measures ANOVAs concerning the mean ERP amplitude were performed for each TW at lateral ROIs with the between-subject factor Group (dyslexics vs. controls) and four within-subject factors, i.e., Grammaticality (correct vs. incorrect), Hemisphere (left vs. right), Region (anterior vs. central vs. posterior), and Salience

(Low vs. Medium). For the midline electrodes (Fz, Cz, Pz), the same analysis was performed, with Group as between-subject factor and Region and Saliency as within-subject factor.

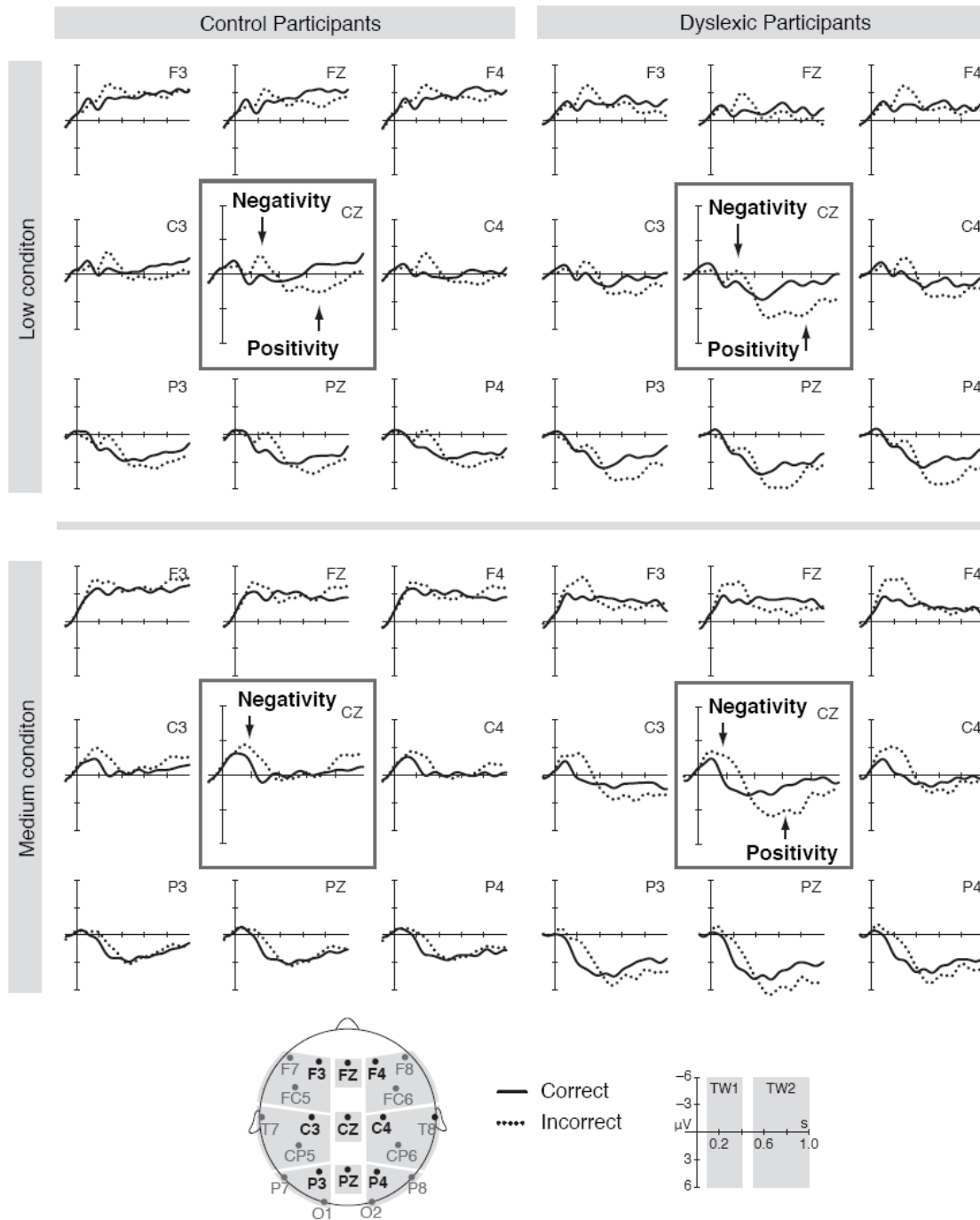


Figure 5.6: Grand average ERPs, separated according to the Saliency manipulation (only Low and Medium conditions). The morpho-syntactically incorrect condition (dot line) is plotted against the correct condition (continuous line). The axis of the ordinates indicates the onset of the suffix. Negative voltage is plotted upward. The plots have been filtered with a 7-Hz low-pass filter for presentation purpose only.

As shown in Table 5.4, in TW 1, a main effect of Grammaticality emerges, both for lateral and midline electrodes. The absence of any interactions between Grammaticality and Hemisphere or Region confirms the observation that the Negativity is broadly distributed. Additionally, the absence of the interaction Grammaticality * Group shows that the ERP component is similarly elicited in both groups.

TW 1 (100-400 ms)	df	Lateral Electrodes		Midline Electrodes	
		F	p-value	F	p-value
Grammaticality	1,24	30.24	< .001	14.82	.001
Gram. * Group	1,24	< 1	< 1	< 1	
Gram * Hemisphere	1,24	2.39	NS	-----	-----
Gram * Region	2,48	< 1		< 1	
Gramm * Saliency	1,24	< 1		< 1	

Table 5.4: Agreement violation experiment: ERP data for TW 1 across control and dyslexic participants (Low and Medium conditions)

For TW 2 (see Table 5.5), the main effect of Grammaticality reaches significance only at midline electrodes, while at lateral electrodes there is an interaction Grammaticality * Region.

TW 2 (500-1000 ms)	df	Lateral Electrodes		Midline Electrodes	
		F	p-value	F	p-value
Grammaticality	1,24	2.602	NS	11.945	< .005
Gram. * Group	1,24	3.225	.084	3.282	.083
Gram * Hemisphere	1,24	1.055	NS	-----	-----
Gram * Region	2,48	4.669	< .05	2.773	.073
Gramm * Saliency	1,24	3.118	.090	3.505	.073

Table 5.5: Agreement violation experiment: ERP data for TW 2 across control and dyslexic participants (Low and Medium conditions)

This interaction was further investigated by paired t-tests separately performed for single regions and revealed that the Positivity is mainly centro-posteriorly localised (Anterior region: $t(25) = -.08$; $p > .05$; Central region: $t(25) = -1.90$; $p = .069$; Posterior region: $t(25) = -2.06$; $p = .05$). A similar trend was found for the midline electrodes, although Grammaticality reaches significance at all electrodes (Fz: $t(25) = -2.12$; $p < .05$; Cz: $t(25) = -3.69$; $p < .005$; Pz: $t(25) = -2.90$; $p < .01$). Interestingly, the interaction Grammaticality * Group also approaches significance for both lateral and midline electrodes. In this case, separate repeated measures ANOVAs for groups show that

Grammaticality is only significant or approaching significance in the dyslexic group (at lateral electrodes: $F(1,12) = 3.94$; $p = .07$; at midline electrodes ($F(1,12) = 11.94$; $p = .005$), and not in the control group. Finally, the interaction Grammaticality * Salience also approaches significance at both lateral and midline electrodes. Based on this interaction and the experimental hypothesis, separate repeated measures ANOVAs were performed for the two conditions.

As shown in Table 5.6, in the Low condition, the main effect of Grammaticality is significant for both lateral and midline electrodes, while for the Medium condition, the interaction Grammaticality * Group approaches (at lateral electrodes) and reaches statistical significance (at midline electrodes). Separate analyses for groups show that for control participants, the main effect of Grammaticality is significant only for the Low condition at the midline electrodes ($F(1,12) = 5.486$; $p < .05$), while it does not reach significance for the Medium condition. For dyslexic participants, the main effect of Grammaticality reaches or approaches statistical significance in all three conditions. These results suggest that only in the control group the amplitude of the Positivity is modulated by the acoustical salience manipulation. As further evidence, in the control group the interaction Grammaticality * Salience is significant at midline electrodes ($F(2,24) = 6.230$; $p < .05$).

		Low			Medium	
		df	F	p-value	F	p-value
Later	Grammaticality	1,24	5.073	< .05	< 1	
	Grammaticality * Group	1,24	1.113	NS	3.232	.085
	Grammaticality * Region	2,48	4.042	< .05	2.092	.077
Mid	Grammaticality	1,24	15.192	.001	1.617	NS
	Grammaticality * Group	1,24	< 1		4.775	< .05
	Grammaticality * Region	2,48	2.913	.087	1.439	NS

Table 5.6: Agreement violation experiment: Separate analyses for the Low, Medium condition in TW 2 (500-1000 ms)

5.4.2.2.2 High condition

ERP results for the High condition are presented in Figure 5.7, that show the presence of the same ERP components in response to morphosyntactic violations in the Low and Medium condition: a broadly distributed Negativity followed by a posteriorly localised Positivity.

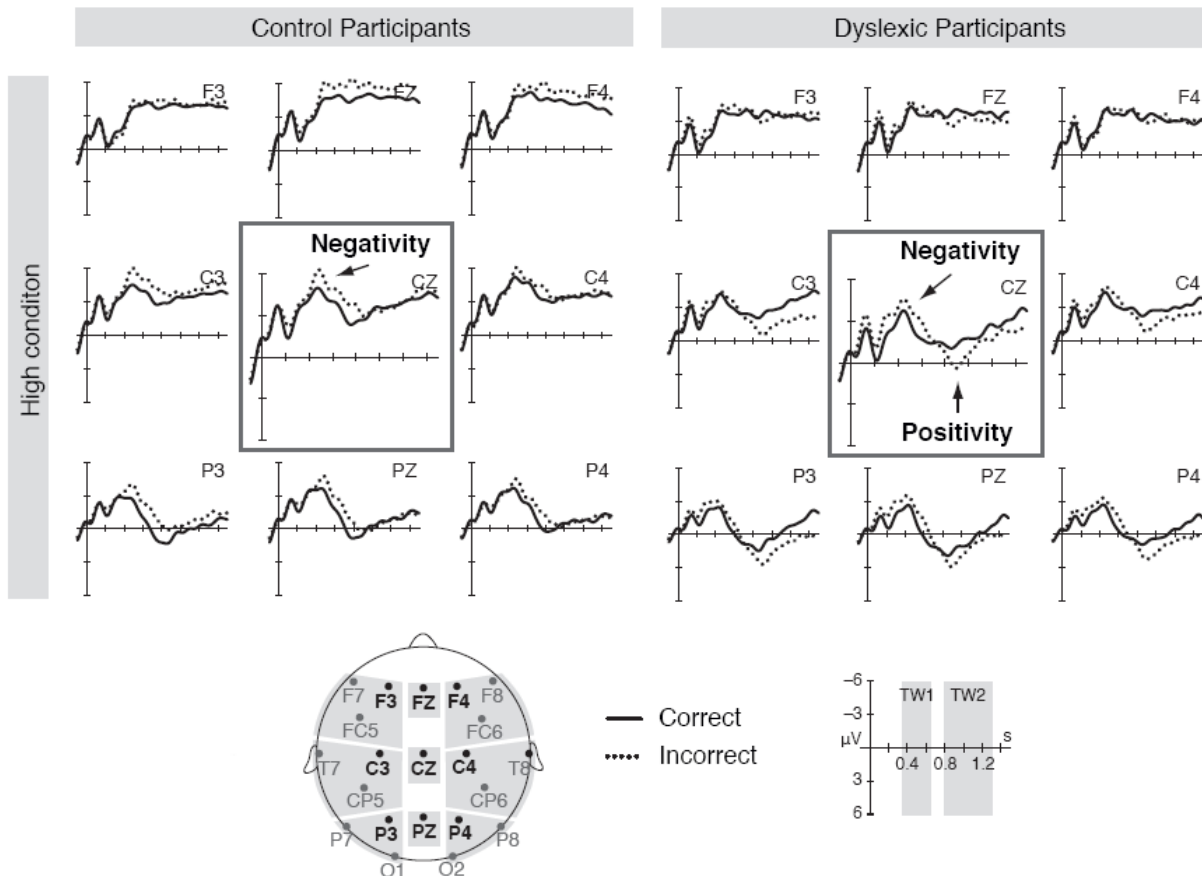


Figure 5.7: Grand average ERPs, separated according to the Salience manipulation (only High condition). The morpho-syntactically incorrect condition (dot line) is plotted against the correct condition (continuous line). The axis of the ordinates indicates the onset of the suffix. Negative voltage is plotted upward. The plots have been filtered with a 7-Hz low-pass filter for presentation purpose only.

Similarly to the analyses performed for the Low and Medium condition, for the High condition statistical analyses were performed on two different TWs, selected on the basis of careful visual inspection of the ERP data. For the Negativity, the TW 350-650 ms was selected, while for the Positivity, the TW 800-1300 ms was selected. Separate repeated measures ANOVAs concerning the mean ERP amplitude were performed for each TW at lateral ROIs with the between-subject factor Group (dyslexics vs. controls) and three within-subject factors, i.e., Grammaticality (correct vs. incorrect), Hemisphere (left vs. right), and Region (anterior vs. central vs. posterior). For the midline electrodes (Fz, Cz, Pz), the same analysis was performed, with Group as between-subject factor and Grammaticality and Region as within-subject factors.

In TW 1 (see Table 5.7), the Negativity reaches statistical significance only at midline electrodes, but not at lateral electrodes. Here, analyses revealed an interaction of Grammaticality * Hemisphere. Given the three-way interaction Grammaticality * Hemisphere * Group, the same repeated measures ANOVAs were calculated in each group, showing that Grammaticality *

Hemisphere was significant only in the control group ($F(1,12) = 5.741; p < .05$), where paired t-tests revealed that the Grammaticality effect is significant in the left hemisphere ($F(12) = 2.76; p < .05$), but not in the right hemisphere.

TW 1 360-650 ms	df	Lateral electrodes		Midline electrodes	
Grammaticality	1,24	1.086	NS	6.741	<.05
Gram. * Group	1,24	< 1		< 1	
Gram. * Hemisphere	1,24	4.293	< .05	---	----
Gram. * Hemisphere * Group	1,24	3.846	.062	---	----
Gram * Region	2,48	< 1		2,48	< 1

Table 5.7: Agreement violation experiment: ERP analyses for the High condition in TW 1 (350-650 ms)

For TW 2 (see Table 5.8), the analyses reveal a significant interaction Grammaticality * Region at midline electrodes. This interaction was further investigated by paired t-tests separately performed for single regions and revealed that the Positivity is mainly posteriorly localised (Anterior region: $t(25) = -.14; p > .05$; Central region: $t(25) = -1.58; p > .05$; Posterior region: $t(25) = -2.14; p < .05$).

Given the interaction Grammaticality * Group approaching significance at lateral electrodes, the same repeated measures ANOVAs were calculated in each group, showing that the Positivity was significant in the dyslexic group (Grammaticality: $F(1,12) = 3.777; p = .076$; Grammaticality * Region: $F(1,12) = 4.547; p < .05$), but not in the control group. Again, paired-tests revealed that the localisation of the Positivity in the dyslexic group was limited to central and posterior regions (Anterior region: $t(12) = -.69; p > .05$; Central region: $t(12) = -2.14; p = .054$; Posterior region: $t(25) = -2.41; p < .05$)

TW 2 800-1300 ms	df	Lateral electrodes		Midline electrodes	
Grammaticality	1,24	2.460	NS	< 1	
Gram. * Group	1,24	4.100	.054	2.292	NS
Gram. * Hemisphere	1,24	1.687	NS		
Gram * Region	2,48	3.866	< .05	2.702	.098

Table 5.8: Agreement violation experiment: ERP analyses for the High condition in TW2 (800-1300 ms)

5.4.2.3 Correlations between morphosyntactic and phonological measures

Pearson correlations were performed between all measures of phonological processing and measures of morphosyntactic processing (Table 5.9). While no significant correlation was found between RT in the grammaticality judgement task and phonological variables, various correlations have been found between accuracy in the grammaticality judgement and phonological skills. Interestingly, the accuracy in the Low condition is the only variable correlating with both phonological processing and rapid naming. When performing separate correlations for the two subject groups, different patterns of correlations were found. In the control group, the accuracy in the grammaticality judgement tasks across conditions correlates with phonological measures (i.e., accuracy in non-word reading) and with rapid naming (i.e., number of RAN errors) (all $p_s < .05$). In the dyslexic group, the accuracy in the grammaticality judgement tasks across all conditions only correlates with phonological measures, particularly accuracy and speed in the phonemic awareness task (Spoonerisms) (all $p_s < .05$).

In order to perform correlations between phonological processing and the ERP correlates of the agreement violation experiment, ERP difference measures were created. For each acoustical salience condition, the correct mean ERP amplitude was subtracted from the incorrect mean amplitude for each TW (averaging across all ROIs for the Negativity, and considering only central and posterior electrodes for the Positivity). As shown in Table 5.9, only a few correlations between ERP measures and phonological variables emerged. While the amplitude of the Negativity (in the High condition) correlates with the RAN, the amplitude of the Positivity (in the Medium condition) correlates with phonological processing measures.

Phonological measures	Morphosyntactic measures								
	Grammaticality judgement: Accuracy			ERP data: Negativity			ERP data: Positivity		
	Low	Med	High	Low	Med	High	Low	Med	High
MMN	-.123	-.088	-.030	-.074	.146	-.249	.300	.113	-.198
NW read. err.	-.461*	-.569**	-.598**	-.123	-.056	.091	.169	.496*	.204
Digit span	.098	.204	.280	.245	-.162	-.030	.208	-.405*	-.149
Spoon: Accuracy	.646**	.736***	.792***	.197	-.014	.100	.087	-.139	-.021
Spoonerisms: RT	-.406	-.635**	-.676**	-.269	-.024	-.130	-.014	.332	.140
NW repetition	.416	.555**	.621**	.358	.139	.240	.205	-.005	-.094
Sent. rep	.401	.490*	.479*	.340	-.190	.205	.227	.085	.098
RAN: Errors	-.464*	-.295	-.262	.118	.156	.464*	.090	-.203	.128
RAN: Time	-.018	-.131	-.114	-.066	.042	.056	.006	.074	.168

* < .05 ** < .01 *** < .001

Table 5.9: Correlations between phonological and morphosyntactic measures

Interestingly, separate analyses for the two groups reveal different patterns of correlations. In the control participants, the amplitude of the Positivity (in the Medium and High condition) correlates with the errors in the RAN ($r(12) = -.566$; $p < .05$ and $r(12) = -.550$; $p = .052$ respectively). In contrast, in the dyslexic group, the amplitude of the Negativity (in the High condition) correlates with errors in the RAN ($r(12) = .637$; $p < .05$), while the amplitude of the Positivity (in the Low condition) correlates with non-word repetition ($r(12) = .629$; $p < .05$)²⁴. These different correlations entail interesting implications in terms of cognitive strategies reflected by the two different ERP components. However, it should be remembered that a note of caution is warranted, given the small number of participants in each group (N ranging from 11 to 13) and the high number of correlations computed.

5.4.3 Discussion

The present study further confirms the existence of morphosyntactic difficulties in DD. Here, only the general presence of morphosyntactic deficits will be discussed, while the reader is directed to the “General discussion” (Section 5.5) for a discussion on the relationship between morphosyntactic and phonological deficits.

In the behavioural grammaticality judgement task, all control and dyslexic participants performed above chance, and no group differences were observed. This is in line with similar tasks reported in previous studies conducted with Dutch and German dyslexic adults (Rispen et al., 2006; Russeler et al., 2007). Similarities can be found also with our previous study conducted on Italian dyslexic adults (see Chapter 3). RTs for the grammaticality judgement, however, revealed longer latencies for the dyslexic group, reflecting general slower processing (Breznitz & Leikin, 2000; Russeler et al., 2007).

Interestingly, when analysing the acoustical salience conditions separately, shorter latencies were found for both groups in the High condition versus the other two conditions, suggesting that the vowel change was effectively used as a cue for the morphosyntactic agreement judgement. The absence of differences between dyslexics and controls in this pattern means that the additional cues is similarly used by both groups. The longer latencies shown by dyslexic participants are thus linked to a general processing slowness.

In the ERP experiment, two main ERP components have been found in response to subject-verb

²⁴ To further investigate the relationship between the amplitude of the Negativity and lexical access, additional Pearson correlations were computed taking into account word reading (both speed and accuracy). Interestingly, the amplitude of the Negativity in the Medium condition was correlated to accuracy in word reading (only in the dyslexic sample), $r(13) = .603$, $p < .05$.

agreement violations: a broadly distributed negativity followed by a posteriorly localised positivity. The Positivity can be interpreted as a P600, as previously reported in studies using the same paradigm (Hasting & Kotz, 2008). The presence of an early negativity, called “[Early] Syntactic Negativity”, in response to auditorily or visually presented word-pairs containing agreement violations has also been previously reported (Hasting & Kotz, 2008; Münte, Heinze, & Mangun, 1993). Its broad topographical distribution, in contrast to the left anterior focus observed in most sentential studies (Friederici, 2002), supports the idea that the processing of isolated two-word utterances may be driven by functionally different mechanisms than those underlying the classical (morpho)syntactic ERP component LAN, and the centroparietal N400 (see Münte & Heinze, 1994).

As discussed by Hasting and Kotz (Hasting & Kotz, 2008; Münte et al., 1993), the evaluation of the syntactic match between pronoun and suffix could be based on the formation and dis-/confirmation of specific phonological expectancies (Pulvermüller & Shtyrov, 2006). When looking at the acoustical salience conditions separately for both groups, differences in the occurrence of the Syntactic Negativity and the Positivity emerged. First of all, while the Syntactic Negativity is elicited in all conditions in both groups, the Positivity primarily occurs in the dyslexic group and seems to reflect an additional effort in processing subject-verb agreement violations. In the literature, the amplitude of the P600 is often associated with syntactic difficulty and with syntactic integration costs (Kaan et al., 2000). In the present study, the Positivity is constantly present in the dyslexic sample, while in the control group it is only elicited by stimuli in the Low condition, i.e., the most difficult condition, characterised by subtle acoustical changes that signal the agreement violation. Both the additional ERP component in response to agreement violations and the longer RTs in the grammaticality judgement task in the dyslexic group point toward greater effort and general “weakness” in morphosyntactic processing in DD. Similarly, in our previous study (Chapter 3) we found the presence of an additional ERP component in Italian dyslexic adults processing subject-verb agreement violations. In this case, however, the additional effort in dyslexic participants was reflected in an N400-like component. The occurrence of a different additional ERP component in Italian can be attributed to the different stimulus material. While in the present study two-word utterances consisting of pronoun and verb have been used, in the Italian study sentences comprised a NP subject, a verb and an adjunct-phrase.

5.5 General discussion: the relationship between phonological and morphosyntactic deficits

The present study aimed at further characterising both phonological and morphosyntactic processing deficits in DD, by means of electrophysiological and behavioural tasks performed by the same dyslexic participants. Moreover, the study directly investigated the interaction between the two linguistic domains, trying to clarify whether the morphosyntactic processing difficulties can be considered a primary deficit, or whether these difficulties should be attributed to more basic phonological/acoustical processing deficits.

We have already seen that both phonological and morphosyntactic deficits have been confirmed by the present study (see Sections 5.3.4 and 5.4.3). The question regarding the nature of the morphosyntactic processing difficulties is however still open. Concerning the relationship between phonological and morphosyntactic processing two different approaches were pursued.

First, in the agreement violation experiment, the verbal inflections were manipulated with respect to their acoustical salience. Here, only subtle modulations of the ERP components by acoustical salience have been found, which, moreover, mainly concern the control participants. We have already seen that for the control participants the Positivity, reflecting increased effort in processing the violations, has been found in the Low condition only. In addition, again in the control participants only, differences in the lateralisation of the Syntactic Negative were observed across conditions. While in the Low and Medium condition, the Syntactic Negativity is equally distributed in the two hemispheres, in the High condition, it is more left lateralised. This finding could be interpreted as reflecting a particular processing strategy used to resolve the agreement violation. In the High condition, the change in the stem of the verb leads to a different word, that is presumably stored as separate unit in the mental lexicon. Thus, the left-lateralisation of the Syntactic Negativity elicited to agreement violations in the control participants could be interpreted as reflecting a strategy related to word retrieval (further discussions related to this point will be provided in light of the existing correlations).

In a second approach, the relationship between phonological and morphosyntactic processing was investigated by relating performance in phonological tasks to both behavioural and ERP measures of morphosyntactic processing. As observed before, a note of caution is warranted, given the small number of participants and the high number of correlations computed. The accuracy in the grammaticality judgement highly correlates with all levels of phonological processing, confirming a general relationship between phonology and morphosyntax. However, only a few correlations were

found between phonological measures and electrophysiological correlates of morphosyntactic processing. Despite their limits, these correlations might provide further possibilities to interpret the different processing strategies reflected by the two observed ERP components. More specifically, while the Positivity in DD participants (especially in the Low condition) seems to be related to phonological processing, the Syntactic Negativity in both groups (especially in the High condition) seems to be related to lexical access, thus further confirming the interpretation that emerged from the left-lateralisation of the Syntactic Negativity. It is conceivable that the Positivity and the Syntactic Negativity reflect different processes for the detection of the morphosyntactic violations, respectively based on phonological and lexical information. While for the control participants the efficient use of processes related to lexical retrieval seem to be enough (at least in the Medium and High condition), dyslexic participants need a further process, presumably related to a conscious analysis of the morphological inflections.

The presence of different strategies to resolve morphosyntactic violations seems to be compatible with recent models describing different ways to process regular and irregular verbs (Ullman, 2001). According to the *Declarative / Procedural (DP) model*, language processing is based on two neurocognitive mechanisms: a declarative memory system consisting of a lexical store of memorised words rooted in temporal lobe structures, and a procedural memory system involved in processing combinatorial rules and rooted in frontal brain structures. Competent native speakers seem to efficiently rely on both mechanisms, while early second-language learners mostly rely on the declarative memory system, as the procedural system is initially not accessible (Morgan-Short et al., 2010; Osterhout et al., 2008; Steinhauer et al., 2006). Similar hypotheses have been proposed for explaining grammatical difficulties in children with SLI (Gopnik et al., 1997; van der Lely, 2005b).

The hypothesis that individuals with DD lack the efficient use of different strategies in morphosyntactic processing has been previously discussed concerning the results of my previous studies on Italian dyslexic adults and children (Chapters 3 and 4). In these studies, the finding of an N400-like component in response to subject-verb agreement violations in adults and children with DD, is interpreted as reflecting dyslexics' reliance on aspects of lexical-semantic predictability, while control participants rather rely on procedural strategies. In the present study, the use of two-word utterances presumably led to the use of different strategies in control participants, who in the easiest conditions just rely on the automatic recognition of violated phonological expectancies. The present results further suggest that dyslexic individuals cannot rely only on these mechanisms and need a further processing strategy, presumably based on phonological processing (as indicated by the correlations) or on procedural rules.

Are the (morpho)syntactic deficits revealed in DD specific or based on an underlying phonological impairment?

Based on the results of the present study, the hypothesis that the morphosyntactic deficits in DD can be traced back to phonological processing deficits cannot be definitely confirmed. The manipulation of the acoustical salience of the verbal inflections seems to have an influence on subject-verb agreement processing in the expected direction only in the control participants. Dyslexic participants' difficulties with the comprehension of morphemes, however, seem not to be based on the acoustical processing of the input, as hypothesised in Leonard's *Surface Hypothesis* (Leonard, 1998) and connectionist models (Joanisse et al., 2000; Shankweiler & Crain, 1986), since the processing problems are not restricted to stimuli with morphemes characterised by low acoustical salience. Additionally, the suggested central role of WM and STM on sentence comprehension in DD (Jiménez et al., 2004; Robertson & Joanisse, 2010; Shankweiler & Crain, 1986) has to be re-evaluated, as the reported general morphosyntactic weakness in DD cannot be explained by the memory load, given the use of very short sentences in the current study.

The correlations between morphosyntactic processing and phonological skills, however, leave open the possibility that morphosyntax is at least modulated by phonology. In particular, the hypothesis of a developmental relationship between phonology and morphosyntax (Chiat, 2001) seems the most adequate to partially explain such a modulation. A primary deficit in phonology might affect the subsequent development of morphosyntactic cues or at least leading to the compensation through different cognitive strategies. A similar developmental explanation, however, cannot be confirmed by the present study, and needs further investigations at different stages of language development.

Appendix 5A: List of verbs used in the morphosyntactic task

	HIGH	MEDIUM	LOW
1	KÖNNEN	SOLLEN	HABEN
2	SEHEN	BRINGEN	MACHEN
3	GEBEN	SAGEN	FINDEN
4	WOLLEN	BRAUCHEN	SCHAFFEN
5	NEHMEN	MEINEN	SUCHEN
6	HALTEN	ZIEHEN	ZAHLEN
7	* GELTEN	BAUEN	ZEIGEN
8	FAHREN	KAUFEN	DENKEN
9	TREFFEN	KENNEN	HEISSEN
10	TRETEN	LERNEN	HÖREN
11	TRAGEN	ZÄHLEN	LEGEN
12	WERFEN	FRAGEN	SCHREIBEN
13	SCHLAGEN	SINGEN	* FLIEßEN
14	MÖGEN	TEILEN	LIEBEN
15	RATEN	TREIBEN	LACHEN
16	LADEN	WÜNSCHEN	BUCHEN
17	BRECHEN	KOCHEN	PACKEN
18	FANGEN	MALEN	SCHWIMMEN
19	BACKEN	MISCHEN	PUTZEN
20	STEHLEN	SCHENKEN	SCHREIEN
21	WASCHEN	FÜLLEN	FILMEN
22	GRABEN	LEHREN	FISCHEN
23	STECHEN	PFEIFEN	KLOPFEN
24	BRATEN	* HEGEN	RAUBEN
25	DÜRFEN	KOMMEN	GEHEN
26	HELFFEN	STEHEN	LIEGEN
27	LAUFEN	SPIELEN	STEIGEN
28	SPRECHEN	BLEIBEN	WARTEN
29	FALLEN	LEBEN	GLAUBEN
30	STERBEN	FEHLEN	HOFFEN
31	SCHLAFEN	RUFEN	SITZEN
32	SAUFEN	FLIEGEN	PASSEN

Chapter 6

General discussion

6.1 Comparison between Italian ERP data (adults vs. children)

A brief comparison of ERP results between Italian adults and children has already been provided in Chapter 4. Although a direct quantitative comparison is not possible, given the differences in EEG data acquisition and processing (see sections 3.2.3.3 and 4.5.1 for further details), here I would present some further remarks, mainly based on a qualitative analysis of the results. Figure 6.1 summarises the main ERP results obtained in Study 1 and Study 2.

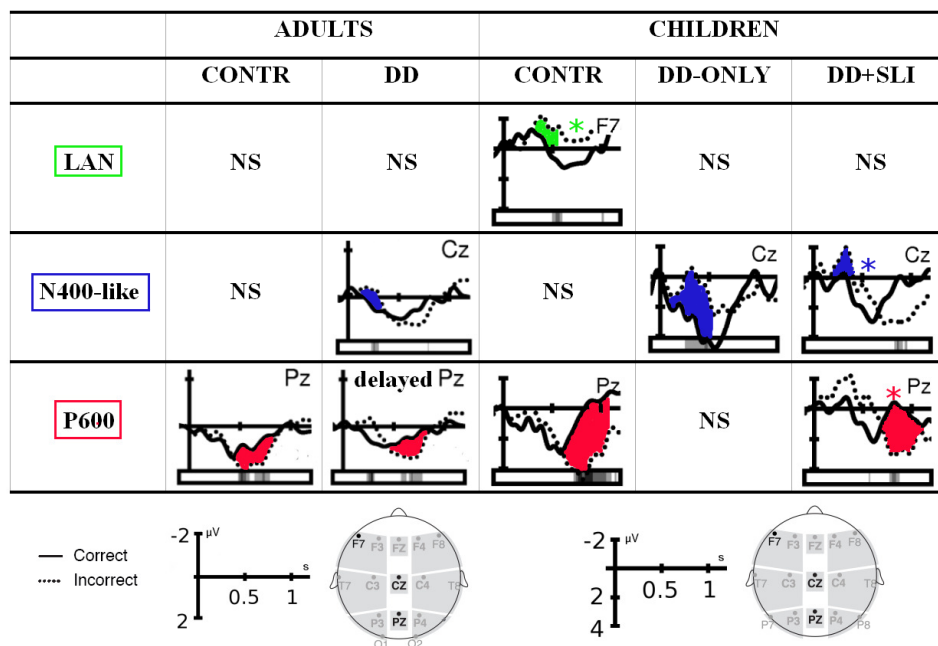


Figure 6.1. Grand average ERPs for Italian adults (controls and dyslexics; Study 1) and Italian children (controls, DD-only, and DD+SLI; Study 2). The morpho-syntactically incorrect condition (dot line) is plotted against the correct condition (continuous line). The axis of the ordinates indicates the onset of the suffix. Negative voltage is plotted upward. The plots have been filtered with a 7-Hz low-pass filter for presentation purpose only. The colour-shaded sections indicate regions of statistical significance. Where * is reported, statistical significance is approached.

First of all it should be noted that children generally show ERP components characterised by higher amplitude and longer latencies. Both these results are widely described in the literature. For example, Männel and Friederici (2008) argued that infant ERPs usually show larger amplitudes than adult data (possibly due to skull thickness) and longer latencies than adult ERPs, which gradually decrease with increasing age. In our case, however, the higher amplitude in children could additionally be due to the different offline filters that have been applied in the two experiments (1-40 Hz in adults and 0.3-40 in children). Whatever the cause of the higher amplitude of components in children with respect to adults, it might explain the counterintuitive finding²⁵ that the LAN is present in control children, but not in control adults.

With respect to dyslexic participants, it is interesting to note the developmental trend. While dyslexic children only show an N400-like component, dyslexic adults also present a P600 (although delayed with respect to their peers). This result points toward a gradual development of a control-like electrophysiological pattern, reflecting more advanced cognitive strategies in dyslexic adults with respect to dyslexic children. However, longitudinal studies are needed in order to confirm this preliminary finding. To our knowledge, to date only one study has directly compared DD children and adults in the same ERP experiment (Hommet et al., 2009). Using an MMN paradigm, they found two components mainly impaired in the dyslexic samples, namely the MMN and the LDN. Similarly to our results, dyslexic children showed anomalies concerning both the components, whereas dyslexic adults showed anomalies only in the MMN, thus revealing a developmental trend gradually approaching the controls' ERP pattern.

Finally, it is also interesting to point out that DD+SLI children present an ERP pattern similar to dyslexic adults. This is a counterintuitive result and needs further investigations. However, it should be noted that both components in DD+SLI children are only approaching statistical significance. This might be explained by high variability within the group. For example, Oberecker (2007) also found a global N400-like + P600 pattern 32-month-old children at risk for SLI in response to syntactic violations, but when the sample was divided according to type of linguistic impairment, different ERP patterns emerged (see Section 2.5.5 for further details). In our study subgroup analyses have not been performed due to the small number of participants (N = 16), but it should be noted that at the behavioural level our DD+SLI children had a very homogenous pattern, as supported by their very low performances in the grammaticality judgement task (individual scores showed that more than 80% of DD+SLI children had a behavioural performance significantly lower than their individually matched controls).

²⁵ The literature comparing ERP response to (morpho)syntactic violations in typically developing children and adults, reviewed in Section 2.4, is consistent in reporting that the LAN is the last component to be shown during development (in particular see Hahne et al., 2004; Silva Pereyra et al., 2005).

6.2 Comparison between ERP data from Italian and German dyslexic adults

A comparison of the ERP results between Italian and German adults has already been provided in Chapter 5. Again, a direct quantitative comparison is not possible, given the differences not only in EEG data acquisition and processing, but also in the experimental paradigm (see Chapter 3 and 5 for further details). Here, only some further remarks, mainly based on a qualitative analysis of the results, will be presented.

Figure 6.2 summarises the main ERP results obtained in Study 1 and Study 3. It is interesting to note that, despite the differences between studies, the ERP results for the two dyslexic samples are very similar. In both cases, subject-verb agreement violations elicited an N400-like component and a P600. However, this is not the case of control participants: in the Italian study they only show a P600 component, whereas in the German study they only show an N400-like component.

This results is puzzling and might be interpreted in different ways. It should be noted that a crosslinguistic comparison between Italian and German data was not the aim of the study, and that a different paradigm has been selected for Study 3. The differences between studies might thus be ascribed to types of stimuli, rather than to the different languages. In fact, in the Italian study sentences containing noun phrase (NP) subject + verb + adjunct phrase were presented (i.e., *La bambina bionda gioca/*giocano con la palla; the blond child plays/*play with the ball*). In the German study shorter and easier two-word utterances were presented (i.e., *Ich gehe/*gehen; I go/*goes*). As already argued, the processing of isolated two-word utterances (as in the German study) may be driven by functionally different mechanisms than those underlying the classical (morpho)syntactic ERP components. Citing Ullman's *Declarative/Procedural (DP)* model (2001), the N400-like component (or Syntactic Negativity) might be related to the declarative memory system, while the P600 component might be related to the procedural system. Applying this model to our results, it might be hypothesised that the N400-like component reflects a sort of comparison of the stimulus to be judged with the lexical form stored into the mental lexicon. In contrast, the P600 component might reflect the application of procedural rules to check the grammaticality of the sentence.

What is particularly interesting is that only control participants use different strategies to resolve different morphosyntactic violations. In particular, they apply the "lexical" strategy with easy two-word utterances, more likely to be present in a similar form in the mental lexicon, and "procedural" rules with more complex sentences. In contrast, dyslexic children do not seem to rely on different

strategies, showing a sort of “rigidity”. In particular, this “rigidity” might be ascribed to the difficulties in a flexible adaptation to the requirements of the task. Alternatively, it might be hypothesised to be due to the limited range of strategies available.

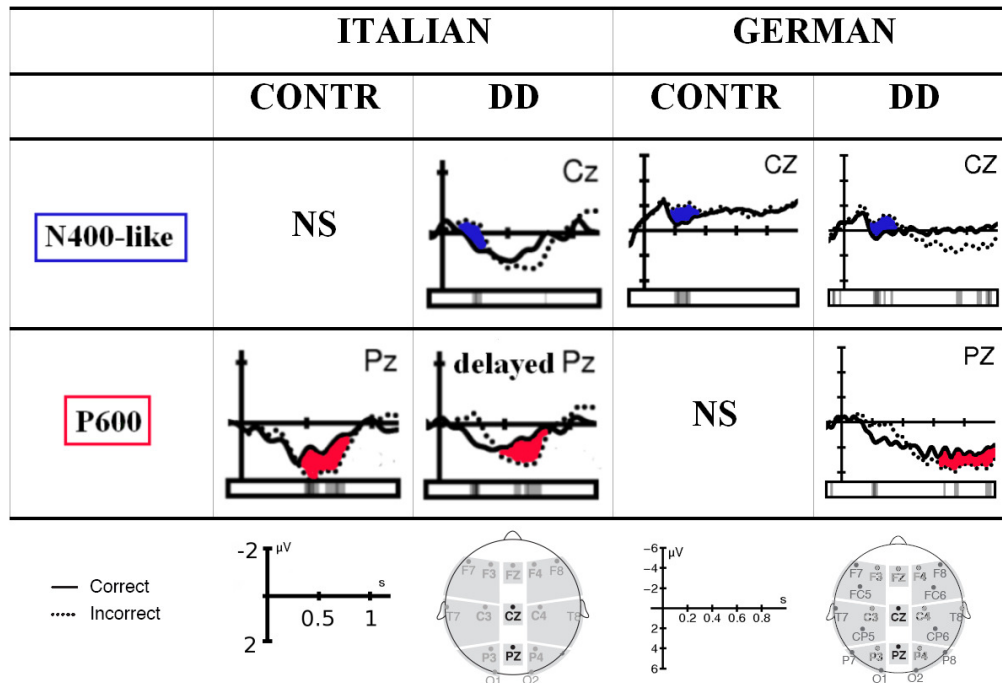


Figure 6.2. Grand average ERPs for Italian adults (controls and dyslexics; Study 1) and German adults (controls and dyslexics; Study 3). For the German participants the three Saliency conditions (High, Medium, Low) have been merged together. The morpho-syntactically incorrect condition (dot line) is plotted against the correct condition (continuous line). The axis of the ordinates indicates the onset of the suffix or the onset of the verb (for the High condition of Study 3 only). Negative voltage is plotted upward. The plots have been filtered with a 7-Hz low-pass filter for presentation purpose only. The colour-shaded Sections indicate regions of statistical significance.

6.3 Conclusion

6.3.1 Is DD characterised by linguistic deficits, mainly involving the morphosyntactic domain?

This question has been the main point of the dissertation, and has been addressed in all the studies, involving different dyslexic populations (Italian dyslexic adults, Italian dyslexic children, German dyslexic adults) and using different behavioural and electrophysiological measures. It should be remembered that in all the studies dyslexic individuals (DD-Only in Study 2) were

carefully selected. None of the participants had a previous diagnosis of SLI or a history of speech and language therapy. Moreover, where possible, the absence of a formal language impairment was confirmed at the moment of testing by standardised linguistic tests.

As expected, the behavioural results do not allow to completely disentangle the question.

In **Study 1** Italian dyslexic adults have been tested. In the grammatical judgement task DD individuals presented performances significantly lower than control participants. Despite the very high performances in both groups, the results appear to be reliable. In fact, the individual scores revealed that more than 60% of dyslexic individuals were characterised by lower accuracy with respect to the mean of controls (< 1 SD).

In **Study 2** Italian dyslexic children were compared to aged-matched controls. In this case two results should be pointed out. First, in the grammatical judgement task (the same that was administered to adults) a difference approaching significance emerged between dyslexic and control children. Also in this case, nearly 70% of the dyslexic children performed more than 1 SD below their matched controls. Second, in the Co.Si.Mo task DD children had worse performance with respect to control children. In particular, the difference is significant in the subtask requiring to produce morphological manipulations of non-words. The fact that this task tests implicit morphosyntactic knowledge (both through the induction of the rule from examples, and through the use of non-words, that prevent from retrieving lexically stored forms) highlights the specific difficulty of DD children in handling derivational morphology.

Finally, from **Study 3**, where German dyslexic adults have been tested, two other findings should be pointed out. First, in the sentence repetition task no differences have been found between dyslexic and control individuals. In this particular case, STM difficulties found when using different tasks (for example non-word repetition or digit span) do not emerge. Again, the presence of contextual and lexical-semantic cues could have helped in performing the task. Second, in the grammaticality judgement task no differences have been found between groups concerning the accuracy. However, when the experiment was repeated to test RTs, significantly slower responses were noticed in dyslexic adults.

The ERP findings show more consistent results. Across all studies dyslexic individuals show an anomalous pattern of electrophysiological activation with respect to the matched controls. Table 6.1 summarises the results of the three studies. In **Study 1** Italian control adults showed a typical P600, whereas their dyslexic peers showed an additional N400-like component preceding the delayed P600. In **Study 2** Italian dyslexic children showed only the same N400-like component, while their control peers had an adult-like pattern (LAN + P600). Finally, in **Study 3** German

dyslexic adults showed the N400-like component (also called Syntactic Negativity) and the P600, while their matched controls only presented the Syntactic Negativity.

	CONTROL PARTICIPANTS	DYSLEXIC PARTICIPANTS
STUDY 1	P600	N400-LIKE Delayed P600
STUDY 2	(LAN) P600	N400-LIKE
STUDY 3	N400-LIKE	N400-LIKE P600

Table 6.1: Summary of the ERP findings across the three studies

The developmental trend shown by Italian dyslexics has already been discussed in Section 6.1. Moreover, the different ERP patterns shown by Italian and German control adults have been discussed in terms of use of the most efficient strategy to resolve the violations (see Section 6.2).

The point that needs further discussion is the nature of the cognitive strategy reflected in the different ERP pattern. First of all, it should be noted that the “alternative” strategy used by dyslexic individuals is less efficient at the behavioural level with respect to the strategy used by controls, both in terms of accuracy in judging the violations (as shown by the Italian behavioural data) and in time required to be applied (as shown by the German behavioural data).

Concerning the nature of the cognitive strategy, it has already been pointed out that it might be a lexical semantic strategy. Different pieces of evidence bring to this conclusion.

First, in the Italian studies the strategy is reflected in an N400-like component. This component has been classically described as reflecting lexical semantic processing (Kutas & Hillyard, 1980a). In particular, it is elicited by lexically anomalous words compared to the preceding sentence context.

Second, the same result (N400-like in response to syntactic violations) has been previously found in special populations, and interpreted as a lexical-semantic compensation. In particular, the literature focuses more on adults learning a second language. According to Ullman’s *Declarative/Procedural (DP)* model (2001), the N400-like found in lower proficient L2 learners reflects that they rely more on the declarative memory system, as the procedural system is initially not accessible. Extending this interpretation to our findings, dyslexic individuals also seem to rely more on the declarative memory system (lexical storage) than on the procedural memory system (the implicit rules for handling inflectional morphology).

Interestingly, there is a third set of evidence confirming this hypothesis. A sort of parallelism has been found between the behavioural and electrophysiological data. In Study 2, dyslexic-only

children showed difficulties when asked to morphologically manipulate non-words. This is exactly the behavioural pattern we should expect based on the hypothesis that they rely more on stored forms than on the procedural rules.

At this point, it seems important to highlight the methodological issues concerning the combination of behavioural and electrophysiological measures. Both measures, alone, were not sufficient to answer our experimental questions. On the one side, behavioural measures are not always sensitive enough to highlight subtle linguistic deficits in dyslexic populations. In addition, they only allow to investigate the result of the cognitive process, as expressed by reaction times and number of errors, without saying nothing about the cognitive process per se. On the other side, ERPs are on-line recordings of the cognitive process under discussion, and provide more sensitive measures with respect to behavioural methods. However, their interpretation is sometime difficult without a behavioural confirmation. In our case, behavioural measures strongly supported the electrophysiological findings, helping in their interpretation.

The presence of morphosyntactic deficits in DD individual entails important practical implications. I have already discussed the importance of using more sensitive linguistic tests in the diagnostic process of children with DD (Section 4.6). Other aspects that need particular attention concern remediation programs and teaching strategies. Since we know that linguistic deficits - mainly concerning morphosyntactic and syntactic skills - are often associated with DD, this should be taken into account when working with children with this disorder, reducing the use of complex verbal instructions, or aiming at check and improve their comprehension.

6.3.2 Are the cognitive deficits underlying DD and SLI the same or different?

This question has been addressed in Study 2, where dyslexic children with and without SLI were compared in different phonological and morphosyntactic measures. The analysis of the neuropsychological and linguistic profiles characterising the two clinical groups has revealed a complex picture concerning the overlap between the two disorders (here only a brief summary of the findings and their interpretation is provided, while for a further discussion the reader is referred to Chapter 4).

It should be noted that the two groups showed exactly the same impairment in reading, but different performances (worse in the DD+SLI group) in tasks tapping linguistic skills such as semantics and syntax. Interestingly, also concerning phonology DD+SLI children mainly performed

worse than dyslexic-only children. However, the differences between the two groups cannot be simply due to a general more severe deficit in the SLI group, as proposed by the *Severity model* (Tallal et al., 1997).

Indeed, qualitatively different performances have been found between the groups in the domain of phonology, but only in certain sub-domains. Our data seem thus more consistent with recent observations pointing toward the presence of different cognitive deficits that could underlie the manifestations of DD and SLI (Pennington, 2006; Pennington & Bishop, 2009). Applying the *multiple overlapping risk factor model* to our data, it could be hypothesised that the two subgroups of dyslexic children (DD-Only vs. DD+SLI) present different patterns of underlying cognitive deficits. In particular, the *component model*, as proposed by Marshall and colleagues (unpublished), provides further explanations for our results (see Figure 6.3 for a schematic representation). Phonology might be break down into several sub-skills, that are supposed to be impaired differently in the two clinical groups. The same approach might be applied to the whole linguistic domain. Whereas DD+SLI (at least in our sample) seem to be impaired in different linguistic domains, DD-Only children are characterised only by morphological deficits. The degree to which these deficits are based on the phonological impairment will be discussed in the next section. However, what seems to be clear is that not all morphological deficits in DD can be ascribed to phonology. As already pointed out, this result is interesting in itself because it highlights the existence of an indefinite border between the two disorders, given the fact that anomalies in the morphosyntactic domain, typically impaired in SLI children, have been found in participants with DD.

A couple of limits of the present study (and reminders for next studies) should be pointed out. First, our results only refer to dyslexic children with and without SLI. We cannot say anything about SLI per se. A comparison with a group of SLI children with preserved reading skills would have notably improved our results and our discussion. However, it has been hard to find children with a clear deficit in linguistic skills and completely preserved reading skills. Children with such characteristics have been described in a number of studies (Bishop et al., 2009; Fraser et al., 2010; Marshall et al., unpublished; Rispens & Parigger, 2010), but not in the Italian population. This is without doubts a point that needs further investigations.

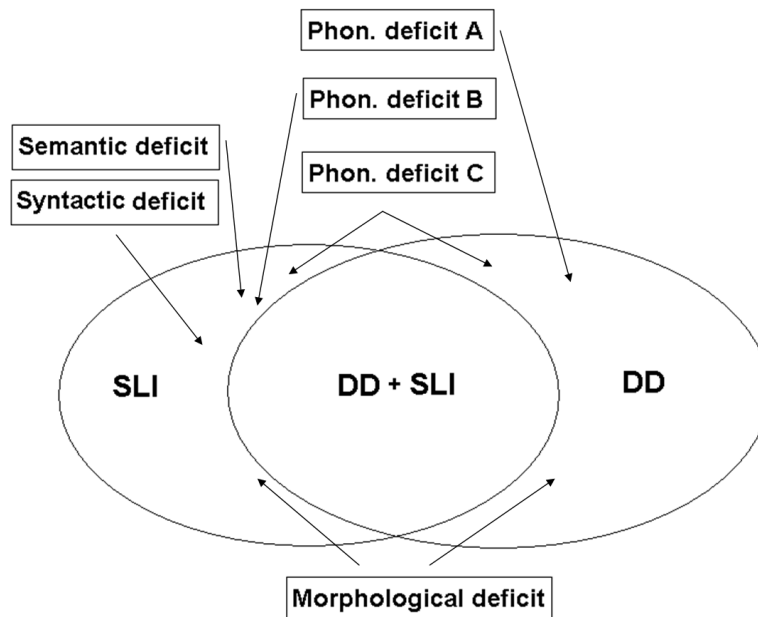


Figure 6.3. Schematic representation of the *Component Model*, adapted from Marshall, Ramus, and van der Lely (2008)

Second, individual profiles might receive more attention. In the present study, the use of ERPs prevents us from investigating individual profiles, as the technique provides more reliable data when group analyses are performed (Luck, 2005). Analyses on the distribution of single scores in the groups for the behavioural tasks are described (see Appendix 4A), showing that, depending on the task, 50% to 80% of children in the DD-Only and the DD+SLI group showed performances significantly below the mean of controls. Although we tried to minimise the variability within groups by keeping them as homogenous as possible, different profiles within the groups might be identified. The indefinite border between disorders might be due to a continuum given by different profiles ranging from few to several associated deficits, as suggested by the *multiple overlapping risk factor model* (Pennington & Bishop, 2009).

6.3.3 Are the (morpho)syntactic deficits revealed in DD specific or based on an underlying phonological impairment?

A third important issue that has been addressed in the dissertation concerns the nature and the specificity of the (morpho)syntactic deficits in DD. As several authors argued, concerning both DD and SLI, the (morpho)syntactic impairment could be based on an underlying phonological deficit, expressed as poor short-term working memory or as a more general phonological processing deficit. This question has been addressed transversally in all the studies, by investigating the relationship between phonological and morphosyntactic measures. In addition, Study 3 provides an explicit

manipulation of the morphosyntactic task, in order to investigate the role of the acoustical salience of the inflections on the sensitivity to subject-verb agreement violations.

Concerning the patterns of statistical correlations between phonological and morphosyntactic measures some notes of caution should be made. First, they reveal nothing about the direction of the effect, meaning that we just can assume that it is phonology that affects morphosyntax and not viceversa²⁶. Second, when performing a high number of correlations (as in our case), it is likely that some correlations appear significant only by chance. In the present studies, I did not systematically apply any statistical corrections, choosing to minimise the risk of Type II rather than type I errors (being particularly interested in general association patterns and taking single emerging correlations very cautiously). Third, correlations might be spurious. For example, when considering two clinical groups (in our case control and dyslexic groups) we might have a correlation between two measures (phonology and morphosyntax) only because one group is worse than the other in both measures. That is why I have also performed correlations in separate groups, thus encountering a further problem that is the small N in each group (max 16).

Keeping these limits in mind, here is a brief summary of the correlations between phonology and morphosyntax across studies. In **Study 1** only a mild correlation between phonemic awareness and ability to judge the grammaticality of sentences has been found in the dyslexic sample, while no correlations emerged between ERP components associated with morphosyntactic processing and phonological measures. In **Study 2** only sporadic correlations have been found between behavioural measures of phonological and morphosyntactic processing. Interestingly, in the DD-Only group correlations emerged between the ability to morphologically manipulate non-words and different phonological measures. In **Study 3** some correlations have been found between behavioural measures of phonological and morphosyntactic processing, while only a few correlations have been found when ERP components have been taken into account. The presence of some correlations leave the door open to the possibility that, at least to some degree, morphosyntax is based on phonology. However, due to the limits reported above, these results cannot lead to strong conclusions.

The direct manipulation of the acoustical salience of verbal inflections could lead to more significant results. Unfortunately, no modulation of the ERP correlates have been found as a function of the acoustical salience of the inflections. Such a modulation has only been found in the control group. However, this result does not help in answering the question..

The definite answer to this question is thus not provided by our data. Here I would like to

²⁶ In our case, our assumptions were driven by the literature supporting an effect of phonology on the developmental of (morpho)syntax both in typical (see the phonological bootstrapping hypothesis, Gleitman & Wanner, 1982) and in atypical (e.g., Chiat, 2001; Leonard, 1998; Rispens & Been, 2007; Shankweiler & Crain, 1986) development.

highlight some points that could be further investigated.

First, the relationship between phonological and morphosyntactic impairment in DD should be better investigated in a developmental perspective. As already pointed out in this dissertation, the phonological impairment shown by our dyslexic participants might have had a role in the development of their morphosyntactic skills. The design of our studies cannot disentangle this possibility. Further studies might investigate these aspects in younger children at risk for DD while they are developing their (morpho)syntactic skills, to further estimate the exact relationship between phonology and morphosyntax.

Second, the results of Study 3 highlight that morphosyntactic difficulties are not due to a particular type of phonological impairment, namely a deficit in perception and acoustical processing of the verbal inflections characterised by low acoustical salience. However, this is only one of the phonological sub-skills affected in DD that might have an influence on (morpho)syntactic development. Other authors proposed WM and STM to be the causes of the (morpho)syntactic impairment in DD (Jiménez et al., 2004; Robertson & Joanisse, 2010; Shankweiler & Crain, 1986). However, based on our data, we could exclude the possibility that STM and WM were the cause of the morphosyntactic impairment, since our stimuli did not have high impact on memory load. Other types of phonological impairments should be put under investigation. Although prosody is a component of phonology that has only been sporadically investigated in DD, it might be an interesting aspect for further research. A number of recent studies (Goswami, Gerson, & Astruc, 2009; Marshall, Harcourt-Brown, Ramus, & Van der Lely, 2009), as well as Sabisch's studies (Sabisch, 2007; Sabisch et al., 2006), have pointed out that at least some aspects of suprasegmental phonology might be impaired in DD. What is particularly important is that prosody has an undisputed role in the acquisition of syntax. According to the *prosodic bootstrapping hypothesis* (Gleitman & Wanner, 1982), it is only through the discovery of prosodically marked units that infants can ultimately acquire the syntactic units of their native language. The role that a possible prosodic deficit in infants at risk for DD might have on their syntactic skills is thus one of the aspects that would be interesting to further investigate.

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