# ERP CORRELATES OF ANOMALOUS MORPHOSYNTACTIC PROCESSING IN ADULTS AND CHILDREN WITH DEVELOPMENTAL DYSLEXIA

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## 1. INTRODUCTION

The linguistic nature of Developmental Dyslexia (DD) is still the object of an open debate, both in the clinical and in the academic environment. As a matter of fact, some individuals with DD show problems involving the linguistic sphere, together with the reading difficulties. 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 (Ramus et al., 2003; Snowling, 2000). Other aspects of language have received less attention. The few studies that have focused on broader linguistic skills (including morphology, syntax, and to a lesser degree semantics) reveal that the linguistic difficulties shown by dyslexic individuals are not restricted to the written language, but are evident in spoken language too.

In particular, behavioural studies have reported impaired comprehension and/or production of complex syntactic constructions, such as relative clauses or passive sentences, in both dyslexic children and adults (e.g., Barshalom, Crain, & Shankweiler, 1993; Robertson & Joanisse, 2010; Waltzman & Cairns, 2000; Wiseheart, Altmann, Park, & Lombardino, 2009). Other 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). In addition, (morpho)syntactic skills have been investigated also in children at risk for DD, generally showing linguistic delays. These latter studies, mostly conducted on preschool children who haven't started formal acquisition of literacy are particularly important, since they suggest that it is not the lack of exposure to printed text that hampers language development.

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. In the light of the broad literature on the comorbidity and overlap between the two disorders (e.g., Bishop & Snowling, 2004), the investigation of the morphosyntactic and syntactic domains in DD is particularly important, given that some morphosyntactic properties are generally impaired in children with SLI.

In the present study, morphosyntactic processing in adults and children with DD has been investigated by means of a particularly sensitive measure, namely event-related potentials (ERPs). According to recent neurocognitive models (Friederici, 2002), a biphasic electrophysiological pattern (LAN/P600) is normally expected in response to morphosyntactic violations, while an N400 component is expected in response to semantic violations. Differences in these electrophysiological components have been sporadically reported in dyslexic participants (Leikin, 2002; Rispens, Been, & Zwarts, 2006, Sabisch, Hahne, Glass, von Suchodoletz, & Friederici, 2006; Russeler, Becker, Johannes, & Münte, 2007), even if linguistic difficulties did not emerge from standardized tests of language comprehension. Interestingly, only two studies have investigated ERP responses to the auditory presentation of (morpho)syntactic violations in individuals with DD. 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, 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). Sabisch et al. (2006) compared the electrophysiological responses to syntactic violations (phrase structure) in typically developing German-speaking children (aged 10 to 12) with those of children with DD and children with SLI. No behavioural difference was found in the sentence correctness judgement task between control and dyslexic children, while SLI children generally performed worse. Concerning ERPs, a similar P600 was found in all groups. However, instead of the early starting LAN shown by control children in response to syntactic violations, dyslexic children presented a delayed LAN (300-600 ms), that was even more delayed in the SLI group (700-1000 ms). These results are discussed in terms of the delay, in dyslexic and SLI children, of the early and presumably highly automatic processes of phrase structure building.

The aim of the present study was to compare ERP correlates of morphosyntactic processing in Italian adults and children with DD both with those of age-matched control participants, and with those of children with a co-diagnosis of DD and SLI. Anomalies with respect to the typical electrophysiological pattern were expected in all the clinical groups. In particular, we expected the dyslexic group with a language impairment to perform worse at the behavioural level, and to show the most anomalous electrophysiological pattern. In addition, a developmental pattern was expected when comparing adults and children in the same group (control adults vs. control children and dyslexic adults vs. dyslexic children).

## 2. METHOD

### 2.1 Participants

Five groups of Italian-speaking participants were included in the study. 16 adults (aged 20-28 years) with DD but without any history of language problems were compared with 16 unimpaired control participants, matched on age and sex. In addition, 16 children (aged 8-12 years) with DD without any history of language problems (DD-only) were compared with 16 unimpaired control participants, matched on age and sex, as well as with 16 children with DD and formal diagnosis of additional SLI (DD+SLI). The inclusion criteria for the dyslexic groups were the formal diagnosis of DD and a current reading speed and/or accuracy 2 SD below the norms as revealed by Italian standardized reading tests (in both text reading tests, Cornoldi & Colpo, 1995, and Judica & De Luca, 2005, and word and non-word reading tests, Sartori, Job, & Tressoldi, 1995). In addition, the children in the DD+SLI group also had a formal diagnosis of SLI, and currently had a performance below 2 SD in standardized test for syntactic comprehension (TCGB, Chilosi & Cipriani, 1995; and/or Co.Si.Mo, Milani et al., 2005). All participants had normal IQ.

### 2.2 Experimental task

The experimental task consisted in 168 Italian sentences including a noun phrase (NP) subject, a present tense main verb and an adjunct phrase (ADJP). 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 (see examples 1-4).

| | | | |
|---|---|---|---|
| (1) | La bambina bionda | Gioca | con la palla |
| | NP singular | VERB singular | ADJP |
| | *the blond child* | *Plays* | *with the ball* |
| (2) | *La bambina bionda | Giocano | con la palla |
| | NP singular | VERB plural | ADJP |
| (3) | Le bambine bionde | Giocano | con la palla |
| | NP plural | VERB plural | ADJP |
| (4) | * Le bambine bionde | Gioca | con la palla |
| | NP plural | VERB singular | ADJP |

All verbs were intransitive, or could be employed intransitively. 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 avoiding differences (with respect to verb length, conjugation, frequency, concreteness etc.) between conditions. All sentences were spoken by two female native speakers of Italian and the recordings were digitalized at a sampling rate of 44.1 kHz (16 bit; stereo).

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. 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 presented. During the experiment, participants listened to the sentences in a quiet room. They were instructed to listen carefully to the sentences, in order to judge their grammaticality. Before the experiment started, 12 practice trials were provided to familiarise the participant with the task.

The procedures for Electroencephalogram (EEG) recording differed between adults and children. EEG in adults was recorded from 15 Ag/AgCl electrodes placed according to the international 10-20 system (Jasper, 1958; F7/8, F3/4, Fz, T7/8, C3/4, Cz, P3/4, Pz, O1/2). EEG data in children were recorded from 19 Ag/AgCl electrodes placed according to the international 10-20 system (with respect to adults FP1/2 and P7/8 were additionally recorded). In all groups, the EEG signal recorded from short-circuit electrodes placed on the right and left mastoids was used as online reference. A further electrode placed on the participant's forehead served as ground electrode. For adults vertical and horizontal eye movements were recorded from two bipolar electrodes, located below and lateral to the left eye, while for children blinks and vertical eyes movements (VEOG) were monitored using two electrodes that were placed above and below the right eye, and horizontal eye movements (HEOG) were recorded from two electrodes located at the outer left and right canthi of the eyes. All electrodes impedances were kept below 5 kΩ (10 kΩ for children). All electrodes were connected to a Neuroscan amplifier (SynAmps vers. 1). The electrophysiological signals were digitalized at the rate of 1000 Hz and offline bandpass zero-phase filtered (1-40 Hz for adults and 0.3-40 Hz for children). The continuous EEG signal was treated with an automatic rejection criterion applied to all electrodes (sections exceeding 70 μV were excluded). ERPs time-locked to the beginning of the critical morpheme (gio'ca vs. gio'cano) were calculated with respect to a baseline (covering the 100 ms prior to this point) for an epoch of 1200 ms.

## 3. RESULTS

### 3.1 Behavioural results

An overall one-way ANOVA on the accuracy in the grammaticality judgement task was performed, with Group as between-subject factor. A main effect of Group emerged, as revealed by Welch-Test for non-omogenuous variances, $F(4,33) = 32.56$, $p < .001$. Post-hoc t-tests (Games-Howell) revealed that all the comparisons between groups were significant, except for the comparison between control and dyslexic adults ($p = .231$) and between dyslexic children with and without SLI ($p = .778$). In particular, control children differed from DD-only ($p = .056$) and from DD+SLI children ( p = .011). Figure 1 shows mean and standard deviation for each group.

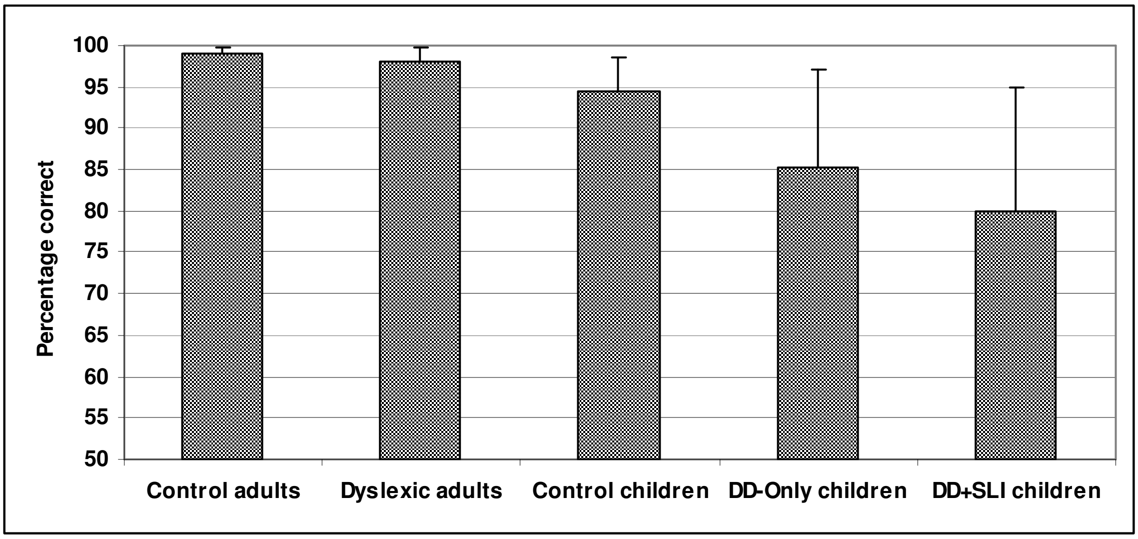


**Figure 1.** Means of percentage correct (and standard deviations) in the grammaticality judgement task

### 3.2 ERP results

Statistical analyses were performed separately for each group. Given the differences in EEG data acquisition and processing between adult and children, only qualitative comparisons between groups will be presented in the Discussion section.

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 for adults and 250-550 and 700-1000 for children). Separate repeated measure ANOVAs on the ERP mean amplitude were performed for each TW in each group. In each analysis 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). In the children analyses P7 and P8 were entered instead of O1 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 each group. In this case, two within-subject factors (Grammaticality and Region) were defined for analysis.

In TW 1, a main effect of Grammaticality emerged in the adult dyslexic group, both at lateral $F(1,15) = 6.18$, $p = .025$ and midline electrodes, $F(1,15) = 7.20$, $p = .017$, and in the children DD-Only group, both at lateral, $F(1,15) = 14.81$, $p = .002$, and midline electrodes, $F(1,15) = 13.87$, $p = .002$. In both groups, no interaction with Region or Hemishere emerged, thus showing the broadly distribution of the component. In the group of children with DD+SLI, the effect of Grammaticality approached significance only at midline, $F(1,15) = 3.75$, $p = .072$, reaching significance when considering the interaction with Region, $F(2,39) = 3.62$, $p = .039$ (paired t-tests showed the posterior localisation of this component). In the two control groups the main effect of Grammaticality was not significant. Only in the children control group the three-level interaction Grammaticality x Hemisphere x Region was significant, $F(2,30) = 5.11$, $p = .012$. Although no significant differences emerged when comparing correct and incorrect conditions for each ROI, a tendency approaching significance (at one-way p-value, given the unidirectional hypothesis) was found at left side (all $p_s < .056$). Given the different localisation, the Negativity in the clinical groups should be interpreted as a N400-like component, while in the children control group it should be better interpreted as a LAN.

In TW 2 a posteriorly localised Positivity emerged in all groups except for the children DD-Only group, as shown by the significant Grammaticality x Region interactions. In particular, the interaction was significant in the adult control group, both at lateral and at midline electrodes, $F(2,30) = 17.37$ $p < .001$ and $F(2,30) = 17.75$ $p < .001$ respectively, in the dyslexic adult group, both at lateral and at midline electrodes, $F(2,30) = 10.94$ $p = .003$ and $F(1,30) = 6.37$ $p = .017$, respectively, and in the children control group, both at lateral and at midline electrodes, $F(2,30) = 12.58$, p < .001 and $F(2,30) = 14.51$, p < .001, respectively. In the group of children with DD+SLI the interaction approached significance at lateral electrodes, $F(2,30) = 3.249$, p = .053, and reached significance only at midline electrodes, $F(2,30) = 4.55$, p = .042. In all cases, following t-tests revealed the posterior lcalisation of the component. Differently, no main effects or interactions emerged in the DD-Only group, showing the complete absence of this component in the group.

Figure 2 shows a graphical summary of the main ERP results in all the groups.

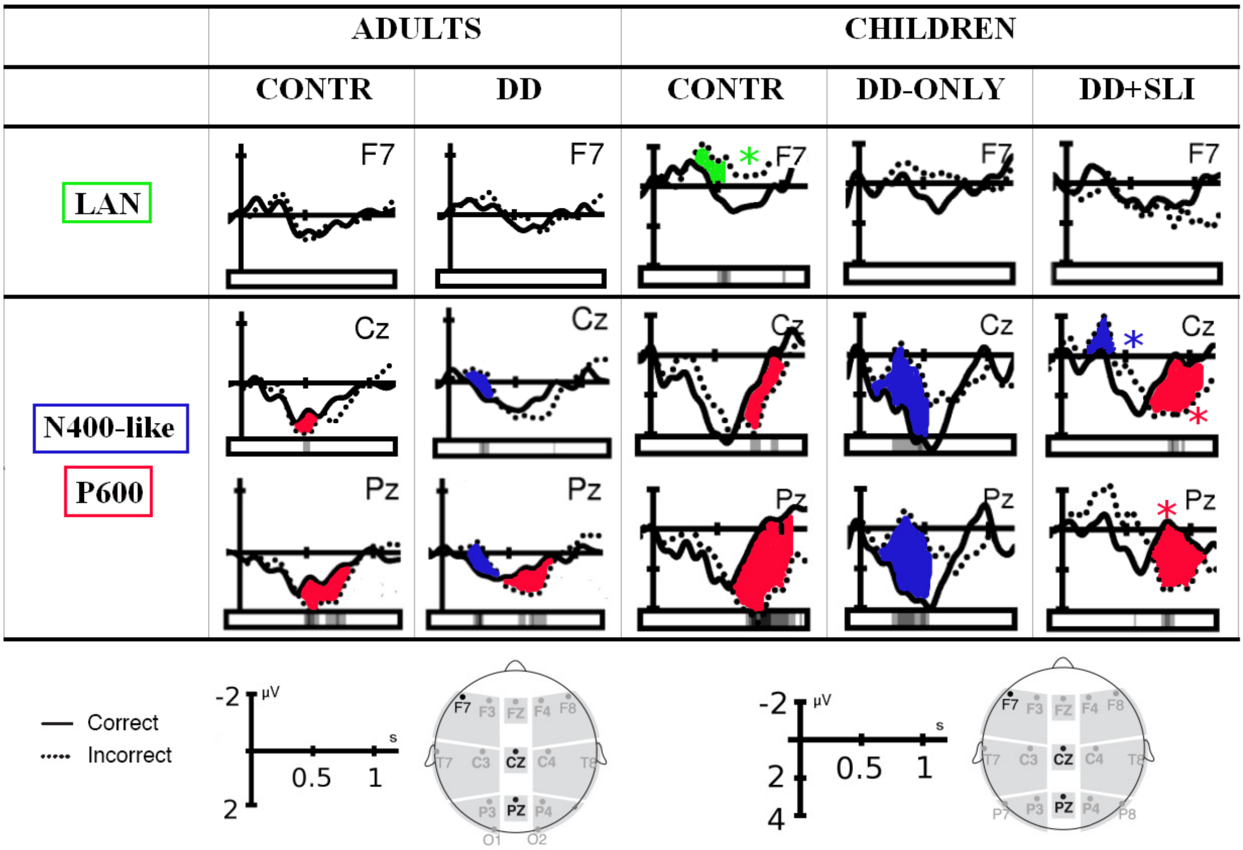


**Figure 2.** Summary of the main ERP results. Grand average ERPs for Italian adults (controls and dyslexics) and Italian children (controls, DD-only, and DD+SLI) are presented for F7 (where the LAN component is typically maximal), for Cz (where the N400-like component is maximal) and for Pz (where the P600 component is typically maximal). 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 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 ($p < .05$), while the additional star indicates $p < .1$

## 4. DISCUSSION

As emerged from the statistical analyses reported in the Results section, and as summarised in Figure 1, different ERP patterns emerged in the three groups in response to subject-verb agreement violations. In particular, in both control groups (adults and children) a broad positive wave (P600) emerged, with slight developmental changes particularly concerning the latency.. In addition, control children showed a significant LAN. Dyslexic participants, irrespectively of age, showed a different electrophysiological pattern, characterized by a Negativity broadly distributed 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). This Negativity was followed by the P600 only in dyslexic adults. Finally, it should be noted that dyslexic children with additional SLI showed an electrophysiological pattern more similar to their control peers (and to control adults). Statistical analyses revealed the presence of the P600 component approaching significance. In addition, a non-robust N400-like component (similar to DD-Only children) emerged, approaching significance only at midline electrodes.

The most striking result concern the presence of the N400-like component in all the clinical groups but not in the control groups. Previous similar evidence of a N400-like component in response to (morpho)syntactic violations was found in studies on SLI children (Fontaneau & Van der Lely, 2008), on aphasic patients (Hagoort, Wassenaar, & Brown, 2003) and on adults learning a second (e.g., Osterhout et al., 2008) or an artificial language (e.g., Morgan-Short, Sanz, Steinhauer, & Ullman, 2010). In these studies, the N400 enhancement is mainly interpreted as reflecting a compensatory strategy, used in order to compensate for difficulties in constructing implicit rules for handling inflectional morphology. In the light of models related to inflectional morphology (see the *Declarative / Procedural (DP) model* proposed by Ullman, 2001) it could be hypothesised that dyslexic participants in our study have difficulties in constructing implicit rules for handling inflectional morphology (procedual system), and thus rely more on storage or ground on aspects of lexical-semantic predictability (declarative memory system), resulting in the N400 enhancement.

In the present study we directly compared the electrophysiological correlates of morphosyntactic processing in dyslexic children with and without SLI. In the literature, only a few studies provide this direct comparison. Sabisch (2007) used the same syntactic paradigm (phrase-structure violation) with DD and SLI children (although not matched for age), and found a similar anomalous pattern, although more deviant in SLI children. Other studies, mainly using paradigms concerning lexical-semantic processing, similarly reported that the electrophysiological anomalies shown by DD individuals occupy an intermediate position between control and SLI participants (Helenius, Parviainen, Paetau, & Salmelin, 2009; Neville Coffey, Holcomb, & Tallal, 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 children have found a lexical-semantical strategy to compensate their difficulty in handling inflectional morphology. Conversely, DD+SLI children do not master this compensatory strategy. They thus rely on the same cognitive strategy used by control children, which however is not efficient at the behavioural level, as shown by the low accuracy scores in the grammaticality judgement task. 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 investigation. 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. In our study subgroup analyses were not performed due to the small number of participants (N = 16), but DD+SLI children's behavioural performance was very homogenous, as shown also by their very low performances in the grammaticality judgement task (more than 80% of DD+SLI children had individual scores significantly lower than their matched control's ones).

A final remark concerns the role of metalinguistic skills in the 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 thus be hypothesised that their problems are more related to metalinguisitc skills. Further studies, however, need to be done in order to confirm this strong and speculative hypothesis.

When comparing data from children and adults, 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. 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 finding[1] 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. This

[1] The literature comparing ERP response to (morpho)syntactic violations in typically developing children and adults, is consistent in reporting that the LAN is the last component to be shown during development (in particular see Hahne, Eckstein, & Friederici, 2004).

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 groups, namely the MMN and the LDN. Similarly to our results, dyslexic children showed anomalies concerning both components, whereas dyslexic adults showed anomalies only in the MMN, thus revealing a developmental trend with increasing similarity to the controls' ERP pattern.

## 5. CONCLUSION

The present results support the hypothesis of different language processing modalities in DD. The need of an additional process related to rule retrieval and/or lexical access confirms a general morphosyntactic processing weakness. This result is particularly relevant within the debate concerning the linguistic nature of DD and its overlap with SLI (e.g., Bishop & Snowling, 2004). On the one hand, the existence of an indefinite border between the two disorders is confirmed, given 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.

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