Chapter 6

Brain responses of dyslexic adults to syntactic violations in spoken language: An ERP study

6.1 Introduction

Chapters 4 and 5 provided experimental data on sensitivity to agreement violations in children with developmental dyslexia. This chapter studies processing of agreement violations and phrase-structure violations in adults with developmental dyslexia. The method of testing is different from that used in the previous chapters. Rather than focusing on the overt linguistic behaviour, the reactions within the brain as a response to syntactic violations will be studied by measuring Event-Related brain Potentials (ERPs). The principle aim of this chapter is to investigate whether the neurophysiological responses to (morpho-)syntactic violations are the same for dyslexic and non-dyslexic subjects.

6.1.1 Event-Related brain Potentials

ERPs provide a non-invasive way of investigating brain activation involved in processing language. ERPs reflect changes in the ongoing electroencephalogram (EEG). The EEG is constituted by the electrical field of pools of neurons which all polarise or depolarise simultaneously. This electrical activity is measured at the scalp and can be time-locked to external stimuli, such as the presentation of a word. The electrical activity related to this external stimulus is then referred to as an ERP. The difference in voltage is considerably small in the continuous EEG and therefore many trials in which the same type of stimulus is presented are averaged to improve the signal strength and to extract the signal from the ‘background noise’ of the EEG. Typically, between 20 and 50 trials of the same event are averaged in order to get an ERP component which reflects an estimate of the time-locked neural activity evoked by the stimulus (Rugg, 1998). ERPs have a high temporal resolution (in milliseconds), compared to other neuro-imaging techniques such as Positron-Emission
Tomography (PET) and functional Magnetic Resonance Imagery (fMRI), but localization of the sources of neural activity is more difficult.

ERP components have been identified that are specifically related to semantic and syntactic processing. Kutas and Hillyard (1980; 1983) reported in their seminal papers that words that are semantically implausible in certain sentence contexts trigger a negative deflection after around 400 milliseconds in comparison with appropriate words (see example 1-2). This ERP component is called the N400, with the N referring to the direction of the deflection of the waveforms (negative) and with 400 indicating the amount of milliseconds it takes for the component to peak.

1. The pizza was too hot to eat
2. The pizza was too hot to drink

At least two ERP components have been associated with processing syntactic information and/or syntactic violations. The first one is a very early left anterior negativity (ELAN) present around 200ms after the onset of a phrase-structure violation, which peaks over the anterior part of the left hemisphere (Friederici, 1995; Friederici et al., 1996; Hahne & Friederici, 1999). In this condition, a noun-phrase context is created by the presence of a preposition or a determiner, but is violated by the presence of a verb form, see 3-4.

3. * Der Freund wurde im besucht
4. Der Freund wurde besucht
(The friend is (in the) visited)

A second ERP component related to syntactic processing is the P600, a positivity which is distributed over the centro-parietal areas of both hemispheres occurring around 600ms after the presentation of a (morpho-)syntactic violation. Violations of gender, number and tense have been reported to trigger a P600 component, as well as phrase-structure violations, or a non-preferred syntactic structure: a so-called ‘garden-path’ sentence (Coulson et al., 1998; Friederici et al., 1996; Gunter et al., 2000; Gunter et al., 1997; Hagoort et al., 1993; Hahne & Friederici, 1999; Osterhout & Mobley, 1995; Osterhout & Nicol, 1999), see sentences 5-7 for examples with the literal translations. Sentence 7 is a garden-path sentence,
as the order of the constituents is object-subject-verb rather than the typical German word order subject-object-verb.

5. *Sie bereist den\textsubscript{masculin} Land\textsubscript{neuter} auf einem kräftigen Kamel
(She travels the land on a strong camel)

6. *The elected officials\textsubscript{plural} hope\textsubscript{singular} to succeed

7. Er wußte das die Sekretärin (\textbf{object}) die Direktorinnen (\textbf{subject}) gesucht \textbf{haben}
(He knew that the secretary the directors sought have)

Based on the existence of these different ERP components, three phases of language comprehension can be distinguished. A first phase in which a parser assigns the syntactic structure of a sentence based on word information (reflected by the ELAN), and a second phase in which lexical-semantic information is processed (reflected by the N400) and in which the verb argument structure information is processed. Finally in the third phase, reanalysis or revision of the syntactic structure (if necessary) takes place (the P600).

Apart from the fact that the ELAN and the P600 reflect different cognitive processes involved in parsing, the components also differ in another way with respect to parsing: whether this is automatic or not. The late positivity has been shown to be sensitive to semantic variables, to attentional demand and to frequency of presentation (Gunter et al., 2000; Gunter & Friederici, 1999; Hahne & Friederici, 1999). Hahne & Friederici (1999), for instance, found that when 80% of the stimulus sentences contained phrase-structure violations, the P600 component was not present, in contrast to the ELAN component. When subjects were presented with the same type of sentences, of which only 20% contained phrase-structure violations, both the P600 and the ELAN components were identified. The authors assume the P600 component to reflect a controlled non-autonomous process of structural reanalysis and repair, in contrast to the ELAN which reflects a highly automatised stage of parsing. Thus, in a situation where the possibility of overall sentence comprehension is diminished, for instance when almost all sentences are ungrammatical, a strategy of a subject may be to drop the attempt to repair all sentences, reflected by an absent P600,
whereas the detection that the phrase-structure is violated is beyond a subject’s control and occurs automatically.

6.1.2 ERPs in developmental dyslexia

The presence and properties of ERP components in developmentally dyslexic readers have been investigated by several researchers. Leikin (2002) studied processing of grammatical functions of nouns (presented visually) in developmental dyslexia. Sentences were presented containing nouns that varied in their syntactic function and position. For instance, a noun could either be the subject, object or the predicate of the sentence (for example, the box is in the kitchen, the boy kicks the box and the package was a box). The amplitude and latency of the P600 was analysed in response to the processing of the nouns. It turned out that the dyslexic participants had longer P600 latencies when they were processing subjects, objects and predicates relative to the control subjects, indicating that processing grammatical information of words is slowed down in dyslexia.

Brandeis et al. (1994) found that peak latencies in the 400-600 ms window (N400 component) of sentences with semantically implausible endings were delayed in dyslexic children compared to the control children. No differences in signal strength were reported. Helenius et al. (1999, 2002b) also investigated neurophysiological responses to semantically implausible sentences in adults with developmental dyslexia, assessing both spoken and written language and using both ERPs and magnetoencephalography (MEG). MEG is a technique that measures the magnetic field caused by synchronous activation of neurons and, similar to ERP, it has good temporal resolution, but in addition it also has good spatial resolution. The ERP data of Helenius et al. (1999) showed that the dyslexic subjects had a delayed N400 component relative to the control subjects when semantic processing was assessed via written materials. The MEG data revealed that the signal was less strong, in addition to being delayed, indicating that smaller or less synchronously activated neural populations are involved in the processing of lexical-semantic information in developmental dyslexia. An MEG study also found the N400 to be delayed in spoken word processing in dyslexic adults relative to control subjects. Helenius et al. (2002ab) furthermore found an abnormally strong N100 response to speech sounds in the left hemisphere of dyslexic
individuals, which was in contrast with the N100 component elicited by non-speech sounds of which all properties (latency, source and amplitude) proved to be the same between dyslexic and non-dyslexic subjects. Combining the findings of the two studies, Helenius et al. (2002b) suggest that the delayed semantic activation is a result of difficulties at the presemantic-phonological stage, as reflected by the abnormally strong response to speech sounds in the left hemisphere.

6.1.3 Goals of present study

The present study focuses on the cortical activation of dyslexic people in response to syntactic violations in spoken language, investigating the presence and properties (amplitude, latency and distribution) of the ELAN and the P600. The peak latencies of the ELAN and the P600 will be of specific interest, as latencies have been found to be delayed for lexical-semantic processing, but have not been investigated as yet in a syntactic violation paradigm for dyslexic individuals. More specifically, sentences containing agreement violations were presented to investigate the P600 component, and phrase-structure violations have been included to elicit the ELAN and the P600 component.

Furthermore, on-line processing of (morpho-)syntactic violations is assessed by means of a grammaticality judgement task, similar to the one described in chapters 4 and 5. Apart from analysing the ERP data, it will also be investigated whether adults with developmental dyslexia are as sensitive to subject-verb agreement and phrase-structure information as control subjects, or whether they have, like children with developmental dyslexia, more difficulty with discriminating between sentences containing agreement violations and correct sentences.

The questions that are addressed in this study are:

1. Do adults with developmental dyslexia differ from normally reading adults with respect to the P600/ELAN components?
2. Are adults with developmental dyslexia as sensitive to subject-verb agreement as normally reading adults?

6.2 Methods

6.2.1 Subjects

Subjects with developmental dyslexia

Twenty subjects with developmental dyslexia (12 males, 8 females, average age: 24) participated in this study. All subjects were native speakers of Dutch, between 18-36 years old, undergraduate students and had normal or corrected-to-normal vision and normal hearing. Two subjects were left-handed and none of the participants suffered from symptoms of neurological disorders.

The subjects were assessed with two reading tasks (single word reading: RWT (Brus & Voeten, 1972) and pseudo-word reading: PWT (Van den Bos et al., 1994)) and a verbal intelligence task (‘similarities’ of the Dutch WISC-R (Van Haasen et al., 1986)) to ascertain their status of developmental dyslexia. The criteria for inclusion in the dyslexic group were: a self reported history of reading/writing difficulties; a standard score on one of the two reading tasks below the 10th percentile, or both scores of the reading aloud words and pseudo-word tasks at least below the 25th percentile; or a difference between the reading aloud pseudo-words and the verbal intelligence task of at least 60 points on the percentile chart; and a score of at least above the 50th percentile on the verbal-intelligence task.

Control subjects

Twenty subjects without developmental dyslexia (8 males, 12 females, average age: 23) participated in the control group. All subjects were right-handed, had normal hearing and normal or corrected-to-normal vision. In order to participate in the control group, subjects had to have a normal history of reading and spelling acquisition and absence of any neurological symptoms.
The control subjects had to score at least above the 50th percentile on the two reading tasks (PWT and RWT) and on the ‘similarities’ task of the WISC-R.

Table 1 shows the age and the mean scores on the two reading tasks and the verbal intelligence task of both groups. Only the performances on the reading tasks proved to be significantly differentiating the two groups ($t>8.30$, $p<0.001$). All subjects were paid for their participation (approximately 15 Euros per session).

<table>
<thead>
<tr>
<th></th>
<th>Control subjects</th>
<th>Dyslexic subjects</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Age</td>
<td>23.2</td>
<td>3.98</td>
<td>24.1</td>
</tr>
<tr>
<td>Reading words</td>
<td>78.5</td>
<td>17.85</td>
<td>23.0</td>
</tr>
<tr>
<td>Reading pseudo words</td>
<td>90.0</td>
<td>10.26</td>
<td>22.25</td>
</tr>
<tr>
<td>Similarities</td>
<td>97.5</td>
<td>6.39</td>
<td>96.0</td>
</tr>
</tbody>
</table>

6.2.2 Materials

The task was a grammaticality judgement task (similar to the ones described in chapters 4 and 5). The on-line continuous EEG was recorded while the participants judged the sentences on their grammaticality. Even though the task has been described in the previous chapters, it will also be explained here, as the experimental set-ups differ.

A total of 250 different Dutch sentences were constructed. Of this set of sentences, 100 were ungrammatical and 150 were grammatical. The 100 experimental ungrammatical sentences included three types of subject-verb agreement violations (each type $n=25$, total $n=75$) and phrase-structure violations ($n=25$). Seventy-five grammatical sentences were constructed matching the subject-verb agreement violations and 25 grammatical sentences were included that matched the phrase-structure violations. Grammatical and ungrammatical counterparts of the experimental sentences were furthermore constructed (see Appendix I). In addition, 50 filler sentences were included. The items were divided over two lists of 250 sentences each and each version of a sentence only appeared on one list so that the
participants only heard one version of a sentence (either the grammatical or the ungrammatical version). Per list, the 250 sentences were pseudo-randomised, divided over 6 blocks (either containing 50 or 25 items) and the presentation of the blocks was pseudo-randomised. Each individual was presented with one list. Subjects were assigned to a list pseudo-randomly and presentation of the two lists was comparable between the two groups.

The Dutch inflectional paradigm allows for at least 3 types of subject-verb agreement violations: linking a singular noun subject to a verb inflected for either the first person singular (type 1) or for plural (type 2) and from linking a plural noun subject to a verb inflected for the third person singular (type 3):

**Type 1:**  
*de wilde tijger *achtervolg/achtervolgt een jongen*  
(the wild tiger *chase/chases a boy).

**Type 2:**  
*de wilde tijger * achtervolgen/achtervolgt een jongen*  
(the wild tiger *chase/chases a boy).

**Type 3:**  
*de wilde tijgers *achtervolgt/achtervolgen een jongen*  
(the wild tigers *chases/chase a boy).

The determiners of the nouns of the last sentence type are all *de*-words (rather than *het* words) so that the determiner is the same in the singular and plural version of the noun (all plural nouns have the determiner *de* rather than *het* in Dutch). Furthermore, all nouns were marked for plural with /s/1. All words following the verb in the first condition and all words, but one, following the verb in the type 2 grammatical sentences start with a phoneme other than a/t/ to prevent co-articulation influences. All lexical items in the sentences were selected from the word list of Kohnstamm et al. (1981) representing the average vocabulary of 6 year old children2.

Twenty-five grammatical fillers were constructed containing a first-person pronoun and a verb inflected for the first-person singular to counterbalance for the fact that the first person singular verb form always was ungrammatical in the first condition:

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1 In Dutch, the lexical form of determiners of singular nouns is either *de* or *het* (depending on gender), but the determiner of plural nouns is always *de*. Nouns can be marked for plural by either the suffix –en or –s.

2 This was done so that it would be possible to assess children with the same materials in an EEG-study allowing for a cross-sectional comparison.
Ik wandel in het bos
(I walk in the forest)

The phrase-structure violations were formed by omitting the noun in a prepositional phrase (PP):

*de jongen heeft in de gezwommen versus de jongen heeft gezwommen
(the boy has in the swum; the boy has swum).

In addition, 25 grammatical fillers were constructed that included a full PP:

De jongen heeft in de zee gezwommen
(the boy has swum in the sea)

The sentences were read aloud by a female speaker at normal speaking rate and they were recorded on a computer. The phrase-structure violations were constructed following the procedure as described in Hahne and Friederici (1999), by reading aloud a sentence with a full PP of which the noun phrase (NP) was cut out post-hoc in order to keep the intonation as natural as possible.

6.2.3 Procedure

The stimuli were presented auditorily via headphones and each of the trials consisted of the following events. The subject was seated in front of a computer screen. One second before sentence-onset a warning tone was presented. The subject was instructed not to move or blink after the warning tone until the visual presentation of three crosses on the computer screen. 1000 ms after the offset of each sentence, three crosses appeared on the computer screen with a duration of 1500 ms, indicating the end of the sentence and the start of the grammaticality judgement task. The subjects were instructed to press either the ‘yes’ or ‘no’ key when the question ‘was this sentence correct?’ appeared on the screen. The response time was maximally three seconds. Each session started with a block of three sentences to practise.
The subjects were tested in one session which lasted maximally three hours including the time needed for electrode application and removal and the screening test for dyslexia.

6.2.4 EEG-recording

EEG-activity was recorded from 32 electrode sites on a standard electrocap (easycap). The electrodes were referenced to the left and right mastoid. Blinks and eye movements were recorded by the electrooculograph (EOG), using four electrodes placed above and under the left eye (to record vertical eye movements) and at the outer left and right cantus (for horizontal eye movements). Neuroscan software was used for the data acquisition and analysis. The EEG and EOG were recorded continuously for each block of sentences with a sample rate of 500 Hz. The signals were amplified and digitised on-line and were stored for later analysis. Epochs containing movement artefacts or eye movements/blinkers were rejected (+/-50 µV) off-line before averaging. The mean percentage of rejected trials was 11% within the group of control subjects and 12% within the group of dyslexic subjects. The ERPs were computed for each participant for 1500 msec time-locked to the onset of the critical verb relative to a 100 ms pre-stimulus baseline. The EEG data were filtered prior to averaging with a 24 Hz low pass filter.

The mean amplitude and latency of the peaks in three different time windows were computed. The waveforms were first visually inspected for an indication of the components. For the subject-verb agreement violations a time window of 900ms-1400 ms post critical verb onset was investigated on the P600 component. This window may seem to be later than expected, but it needs to be taken into account that when materials are presented auditorily rather than visually, it takes longer to fully perceive the word. The mean difference between word-onset and point of disambiguation (the point where one can unambiguously decide whether the verb is inflected correctly or not) was 316 ms (SD 116 ms) for the ungrammatical verbs and 330 ms (SD 105 ms) for the grammatical counterparts\(^3\). Subtracting the time differences between word onset and word offset results in the classic P600 time

\(^3\) This point was calculated by oral and visual inspection of the speech waves, using the software program Cool Edit Pro. The onset of the word following the correct verbs and the onset of the ungrammatical inflections were taken as points of disambiguation.
window (see Friederici et al., 1996 for a comparable methodology). For the phrase-structure violations, the mean latencies and amplitudes in the 200-400 ms and the 700-1200 ms time windows after critical word onset were calculated to investigate the presence of the ELAN and P600 effects.

6.2.5 Data analysis

6.2.5.1 Behavioural data

The responses of the subjects were divided into ‘hits’ ('yes' to a grammatical sentence) and ‘correct rejections’ ('no' to an ungrammatical sentence). The percentages correct on each condition for each group were calculated.

6.2.5.2 ERP data

Repeated measures analyses of variance were carried out. Twenty electrodes were selected for analysis and they were divided over 5 areas: left (FT7, FC3, F3 & F7) and right anterior (FT8, FC4, F4 & F8), left (O1, P7, P3 & CP3) and right (O2, P4, P8 & CP4) posterior and midline (OZ, PZ, CPZ and CZ). These electrodes were chosen as they have repeatedly been shown to correlate with the ERP effects under investigation.

For the subject-verb agreement condition, the within-subject factors were Grammaticality (grammatical versus ungrammatical sentences), Sentence Type (type 1, 2 and 3 subject-verb agreement conditions), Region (the different brain areas) and Electrode (the electrodes within a brain region). The grammatical counterparts of sentence types 1 and 2 are the same, and were therefore taken together in the analysis.

For the phrase-structure condition, factors were Grammaticality and Electrode. For comparison between the controls and the dyslexic subjects, Group was the between-subjects factor. If there was more than one degree of freedom in the numerator, the Greenhouse-Geisser correction was applied (Stevens, 1996). Below, the uncorrected degrees of freedom are reported with the corrected probabilities.
Chapter 6

6.3 Results

6.3.1 Behavioural data

The results of the grammaticality judgement task were calculated with respect to the accuracy of the responses. Both groups scored at ceiling-level (96%-100% correctly; see Table 2). Therefore, no further analyses have been carried out.

<table>
<thead>
<tr>
<th>Sentence Type</th>
<th>Control</th>
<th>Dyslexia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Type 1 Gram.</td>
<td>0.99</td>
<td>0.97</td>
</tr>
<tr>
<td>Type 1 Ungram.</td>
<td>0.99</td>
<td>0.96</td>
</tr>
<tr>
<td>Type 2 Gram.</td>
<td>1.0</td>
<td>0.97</td>
</tr>
<tr>
<td>Type 2 Ungram.</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>Type 3 Gram.</td>
<td>0.98</td>
<td>0.96</td>
</tr>
<tr>
<td>Type 3 Ungram.</td>
<td>1.0</td>
<td>0.98</td>
</tr>
<tr>
<td>Phrase-structure Gram.</td>
<td>1.0</td>
<td>0.98</td>
</tr>
<tr>
<td>Phrase-structure Ungram.</td>
<td>1.0</td>
<td>0.98</td>
</tr>
</tbody>
</table>

6.3.2 The ERP data

6.3.2.1 Phrase-structure violations

ELAN

The ELAN was found in both the control and dyslexic subjects in the left anterior region (control group: F(1,19)=14.31, p<0.001, dyslexic group: F(1,19)=5.77, p<0.03, see Table 3). Both groups taken together, there was a highly significant effect of grammaticality (F(1,38)=19.18, p<0.001) in the left anterior region, but no significant interactions of
Grammaticality and Group, nor Electrode and Group (F<1.0, p>0.32). Figure 1 and 2 show the distribution of the ELAN in both groups.

The latency of the peak was around 40 milliseconds earlier for the dyslexic subjects than the controls, which was a significant difference (F(1,38)=6.68, p<0.02).

P600

The group of control subjects showed a marginally significant grammaticality effect in the left and right parietal region in response to the phrase-structure violations (F>3.48, p<0.08, see Table 3) in contrast with the dyslexic subjects who did not demonstrate a P600 effect (F<0.93, p>0.35, see Table 3 and Figures 1 and 2).

Table 3. Mean latency (in milliseconds) and amplitude (difference between ungrammatical and grammatical conditions) in the different brain regions. Within-subject differences (the ELAN and the P600 component) are indicated with the asterixes: *** p<0.001, **p<0.05, *p<0.1. Between-group differences are indicated with the F-value and P-value in the last two columns.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Control</th>
<th>Dyslexia</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ELAN Amplitude (microvolt)</strong></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELAN Amplitude</td>
<td>-1.58*** (1.87)</td>
<td>-0.99** (1.85)</td>
<td>1.0</td>
<td>0.32</td>
</tr>
<tr>
<td>ELAN Latency (milliseconds)</td>
<td>323 (39)</td>
<td>285 (53)</td>
<td>6.68</td>
<td>0.01**</td>
</tr>
<tr>
<td><strong>Phrase-structure violations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P600 Left Posterior Amplitude</td>
<td>0.62* (1.46)</td>
<td>0.11 (2.28)</td>
<td>0.71</td>
<td>0.41</td>
</tr>
<tr>
<td>P600 Right Posterior Amplitude</td>
<td>0.89* (2.15)</td>
<td>0.61 (2.84)</td>
<td>0.13</td>
<td>0.72</td>
</tr>
<tr>
<td>P600 Centro-Parietal Amplitude</td>
<td>0.32 (2.27)</td>
<td>-0.03 (2.14)</td>
<td>0.25</td>
<td>0.62</td>
</tr>
<tr>
<td><strong>Phrase-structure violations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P600 Left Posterior Latency</td>
<td>923 (115)</td>
<td>964 (131)</td>
<td>1.07</td>
<td>0.31</td>
</tr>
<tr>
<td>P600 Right Posterior Latency</td>
<td>945 (120)</td>
<td>949 (145)</td>
<td>0.007</td>
<td>0.93</td>
</tr>
<tr>
<td>P600 Centro-Posterior Latency</td>
<td>922 (99)</td>
<td>980 (145)</td>
<td>2.13</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Figure 1: The grand average ERPs of the control group for the phrase-structure condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 2: The grand average ERPs of the dyslexic group for the phrase-structure condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Both groups showed significant effects of grammaticality when the three sentence types were taken together in the right posterior regions and in the midline, indicating the presence of the P600, see Table 4 and Figures 3 & 4. The control group also demonstrated a significant effect of grammaticality in the left posterior region, whereas the grammaticality effect did not reach significance (p=0.07) in that area for the dyslexic individuals. Since effects of sentence type were found for both groups (dyslexic group: F(2,38)=7.07, p<0.01; control group: F(2,38)=3.08, p<0.06), the three types were analysed separately, revealing that the dyslexic subjects did not show a significant P600 effect in response to the type 3 violations in any of the three brain regions, in contrast with sentence types 1 and 2, see Table 5 and Figures 5-10. The controls also showed a different distribution of the P600 component in response to the type 3 violations compared with the late positivity triggered by the type 1 and 2 violations: the left posterior region did not show a grammaticality effect for this sentence type.

Both groups taken together, a significant main effect of grammaticality was found in the centro-parietal brain area (F(1,38)=23.6, p<0.001). The between-subjects factor Group did not interact with the factor Grammaticality when the three sentence types were taken together (F(1,38)=1.23, p>0.28), but it did with Sentence Type (F(2,76)=5.37, p<0.007), which reflected the fact that sentence type 3 did not elicit a P600 component in the dyslexic group, as stated above. It furthermore indicated that for sentence types 1 and 2, significant interactions between Group * Electrode * Grammaticality existed in the right posterior (sentence type 1: p=0.009) and midline region (sentence type 2: p=0.05), see Table 6. Further scrutiny of the data showed that these interactions reflect a significant grammaticality effect for sentence type 1 on all electrodes in the right posterior region for the control subjects, but not for the dyslexic subjects (control group: p<0.019; dyslexic group: p>0.08), and that there was a significant grammaticality effect for sentence type 2 on electrode CZ for the controls, but not for the dyslexic individuals (control group: p=0.015; dyslexic group: p=0.1). There was furthermore a trend (p=0.08) for a Group * Electrode * Grammaticality interaction for sentence type 2 in the left posterior region. On electrode CP3, a grammaticality effect was detected for the control subjects, but not for the dyslexic subjects (control group: p=0.002, dyslexic group: p=0.07), whereas the dyslexic individuals showed a grammaticality effect on electrode O1, but not the controls (control group: p=0.48, dyslexic group: p=0.014).
Table 4. The mean latency and amplitude of the P600 component across the three sentence types (grammaticality effect is indicated by the asterixes *** p<0.001, **p<0.05, *p<0.1) in the different brain regions. Between-group differences are indicated with the F and P-values in the last column.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Control</th>
<th>Dyslexia</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject-Verb agreement violations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P600 Left Posterior Amplitude</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>F-value</td>
<td>P-value</td>
</tr>
<tr>
<td></td>
<td>1.36** (2.17)</td>
<td>0.65* (1.51)</td>
<td>1.45</td>
<td>0.24</td>
</tr>
<tr>
<td>P600 Right Posterior Amplitude</td>
<td>1.57*** (1.71)</td>
<td>1.31** (1.56)</td>
<td>0.46</td>
<td>0.50</td>
</tr>
<tr>
<td>P600 Centro-Parietal Amplitude</td>
<td>1.80** (2.28)</td>
<td>1.07** (1.51)</td>
<td>1.42</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Table 5: The probability scores for the three subject-verb agreement conditions in three centro-parietal brain regions. Significant differences are printed in bold; tendencies are printed in italics.

<table>
<thead>
<tr>
<th>Control group</th>
<th>Midline</th>
<th>Right posterior</th>
<th>Left posterior</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F-value   P-value</td>
<td>F-value   P-value</td>
<td>F-value   P-value</td>
</tr>
<tr>
<td></td>
<td>(1,19)</td>
<td>(1,19)</td>
<td>(1,19)</td>
</tr>
<tr>
<td>Type 1</td>
<td>14.04     <strong>0.001</strong></td>
<td>5.36      <strong>0.001</strong></td>
<td>7.01    <strong>0.016</strong></td>
</tr>
<tr>
<td>Type 2</td>
<td>13.89     <strong>0.001</strong></td>
<td>5.99      <strong>0.02</strong></td>
<td>6.48    <strong>0.02</strong></td>
</tr>
<tr>
<td>Type 3</td>
<td>3.23      <strong>0.09</strong></td>
<td>6.06      <strong>0.02</strong></td>
<td>2.61    0.12</td>
</tr>
</tbody>
</table>

| Dyslexic group                        |                       |                       |                  |
|                                       |                       |                       |                  |
|                                       |                       |                       |                  |
| Type 1                                | 3.12      **0.09**    | 5.77      0.027       | 0.74    0.39     |
| Type 2                                | 12.6      **0.002**   | 16.3      **0.001**   | 10.6    **0.004** |
| Type 3                                | 0.42      0.5         | 0.88      0.36        | 0.28    0.6      |
Figure 3: The grand average ERPs of the control group for the subject-verb agreement conditions. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 4: The grand average ERPs of the dyslexic group for the subject-verb agreement conditions. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 5: The grand average ERPs of the control group for the type 1 subject-verb agreement condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 6: The grand average ERPs of the dyslexic group for the type 1 subject-verb agreement condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 7: The grand average ERPs of the control group for the type 2 subject-verb agreement condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 8: The grand average ERPs of the dyslexic group for the type 2 subject-verb agreement condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 9: The grand average ERPs of the control group for the type 3 subject-verb agreement condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Figure 10: The grand average ERPs of the dyslexic group for the type 3 subject-verb agreement condition. Grammatical sentences are represented by the grey line, ungrammatical sentences by the black line.
Table 6: Probability scores for the interactions: Group * Grammaticality * Electrode in the three centro-parietal brain regions for the time window 900-1400 ms post critical-verb onset. Significant differences are printed in bold; tendencies in italics.

<table>
<thead>
<tr>
<th></th>
<th>Midline</th>
<th></th>
<th>Right posterior</th>
<th></th>
<th>Left posterior</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F-value</td>
<td>P-value</td>
<td>F-value</td>
<td>P-value</td>
<td>F-value</td>
<td>P-value</td>
</tr>
<tr>
<td></td>
<td>(3,114)</td>
<td></td>
<td>(3,114)</td>
<td></td>
<td>(3,114)</td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>1.67</td>
<td>0.19</td>
<td>7.65</td>
<td><strong>0.009</strong></td>
<td>0.13</td>
<td>0.89</td>
</tr>
<tr>
<td>Type 2</td>
<td>2.85</td>
<td><strong>0.048</strong></td>
<td>0.33</td>
<td>0.75</td>
<td>2.26</td>
<td><strong>0.08</strong></td>
</tr>
</tbody>
</table>

Visual inspection of the waveforms of the three grammatical sentences that match the subject-verb agreement violations, revealed that the type 3 sentences (with a plural noun) were more positive than the grammatical sentences with a singular noun (type 1 and 2 grammatical sentences). There was no significant difference between the two grammatical sentence types for the control group (F(1,19)=0.09, p=0.35), whereas there was a trend for the dyslexic group (F(1,19)=3.73, p=0.068), with the type 3 sentences being more positive than the grammatical sentences of conditions 1 and 2.

6.3.2.3 Peak latency

The analysis of the peak latency of the P600 revealed a significant difference in the left posterior region between the two groups when all three sentence types were taken together. The peak was approximately 72 milliseconds earlier for the controls (F(1,38)=13.1, p=0.001).

As has been described above, there was no significant grammaticality effect for sentence type 3 in the subjects with developmental dyslexia, and therefore the latency of the P600 component was also analysed for sentence type 1 and 2, excluding type 3 (in both groups, there was a reliable grammaticality effect for sentence type 1 and 2 in the centro-parietal region (dyslexic group: F(1,19)=12.04, p=0.003; control group: F(1,19)=18.37, p<0.001)). This analysis revealed that the peak of the latency of the P600 component in the left posterior region was around 40 milliseconds earlier for the controls relative to the dyslexic subjects, which was a marginally significant difference (F(1,38)=3.32, p=0.076). The latency peaks of the P600 component in the right posterior region and in the midline did not differ between the two groups (F<0.78, p>0.38).
6.4 Discussion

In this study, the presence and properties of two ERP components reflecting syntactic parsing processes have been investigated in dyslexic and normal readers. The main goal of this study was to explore whether dyslexic readers differ from non-impaired readers in parsing spoken language and whether processing syntactic information is delayed in dyslexic readers, akin to processing lexical-semantic information. Furthermore, a second question was whether dyslexic adults are as sensitive to subject-verb agreement as normally reading subjects.

To start with the latter question, the data did not indicate a difficulty with the judgement of subject-verb agreement violations for the dyslexic individuals as all scored at-ceiling level. Some subjects made a few judgement errors, but that was also the case for the controls. These data differ from the grammaticality judgement data of dyslexic children in kindergarten or in primary school, as described in chapters 4 and 5, in the sense that in both populations the dyslexic children were outperformed by the control children. The next chapter discusses a cross-sectional comparison of the three subject groups. The paragraphs below will consider the ERP data.

6.4.1 ELAN

In several studies, it has been found that phrase-structure violations trigger early negative deflections of the brain waves in the left frontal region. Both groups of participants showed this effect between 200-400 ms post critical word onset. No major differences in the distribution of the ELAN between the two groups were detected, but the ELAN peaked significantly earlier in the dyslexic group. The ELAN has been assumed to reflect a highly automatised processing phase of syntactic parsing (cf. Hahne & Friederici, 1999). The results of the present study indicate that dyslexic individuals also make use of this very early mechanism and that they detect these violations even faster than the controls.
Overall, the distribution pattern of the P600 in response to the agreement violations that was found in the dyslexic subjects was relatively similar to the one observed in the control subjects. The brain regions of the control group in which a robust late positivity was present, were also the ones demonstrating an effect in the dyslexic group. Nevertheless, there were differences found with respect to the late positivity. In particular, the dyslexic subjects processed sentences with a plural NP subject different than the control subjects: the P600 was not found in the dyslexic group for this condition. It can be noted in the grand average ERP of this condition that the ungrammatical sentences elicited an increased positivity, but that the grammatical versions (sentences with a plural noun subject and a verb inflected for plural) also triggered more positive waves than the grammatical sentences of the other two conditions, which may have masked the P600. The question is then why the dyslexic subjects show a –statistically not robust- positivity in response to the grammatical sentences, possibly obscuring the late positivity in response to the ungrammatical counterparts. One possibility that deserves further investigation is that a plural NP puts more burden on the sentence processing mechanism than a singular NP, since plural NPs are more complex in terms of semantic and discourse operations, as suggested by Kaan (2002). She found that the P600 component was delayed and smaller in a group of healthy Dutch-speaking adults when plural NPs preceded the ungrammatical verb, in contrast to singular NPs. She hypothesizes that plural NPs burden the diagnosis/repair processes at the verb when the verb does not match the subject in number. Thus, it could be the case that the presence of the plural NP in the type 3 condition has hampered the syntactic repair process in the dyslexic group, reflected in an absent P600 component. In this scenario, the extra processing load of the plural NP in the grammatical sentences could furthermore be responsible for the slightly enhanced positivity measured at the verb. The data suggest that the dyslexic group was more affected by the processing demands of the plural NP than the control group. However, in this group the P600 was also diminished compared to the other two sentence types that contained singular NPs as subjects: only in the right posterior region a reliable effect of grammaticality was found.

Further differences were found in the regions in which the P600 component was present. All sentence types taken together, there was a trend for an effect of grammaticality
in the left posterior region, whereas significant grammaticality effects were observed in the right posterior and midline regions for the dyslexic subjects. In the midline section and in the left posterior region, there was no statistically robust positivity triggered by the type 1 sentences in the dyslexic group, in contrast with the control group. Thus, it seems that the distribution of the P600 is more restricted in the dyslexic group compared to the controls. The P600 component is most prominent in the right posterior region for the dyslexic group, where it was found in response to the type 1 and 2 sentences, but less strong in the left posterior and midline regions.

Pugh et al. (2000) found the left temporo-parietal brain circuit to be disrupted in dyslexic subjects (see chapter 2). In their fMRI study, underactivation of the left posterior region was compensated for by an engagement of the right hemisphere homologues of the left posterior region. The observed pattern of brain behaviour of the dyslexic group in the present study may be stemming from the mechanism as proposed by Pugh et al. (2000). A functional problem in the left posterior region may explain the weaker activation in that area for the dyslexic subjects. However, localisation of brain activation underlying ERP components involved in language processing is difficult due to the so-called inverse problem\(^1\). Even though a source for a particular electric field can be defined, there is an infinite number of sources that can generate such an electrical field. It has to be kept in mind that the observed distribution of an ERP component cannot be mapped directly to the generator(s) of the electrical activation. Therefore, a neurobiological interpretation of the differences in the P600 component between the dyslexic and control subjects can only be done on a speculative basis.

Another difference between the two groups was that there was a statistically not very robust late positivity in response to the phrase-structure violations in the control group, which was absent in the dyslexic group. This may have been caused by the methodology. The critical words were sentence final and the P600 component could therefore have been influenced by sentence final wrap-up effects, as discussed by Osterhout & Holcomb (1995). They report that words at the last position of an unacceptable sentence generally elicit a negativity. If the sentence-final participles in the ungrammatical sentences indeed triggered a negativity, this may have masked a potential P600 component. As almost all amplitudes of

\(^1\) There are techniques that address the localisation of electrical activation measured with an EEG. An example is LORETA (Pascal-Marqui et al. (1994)).
the brain waves in response to the critical words are smaller in the dyslexic subjects compared to the control participants, a possible P600 component will be even harder to detect in the dyslexic group, since the difference between the ungrammatical and grammatical waves will be relatively smaller than the difference between the two in the control group.

Adding to other ERP evidence on delayed linguistic processing in dyslexic individuals (Brandeis et al., 1994; Helenius et al., 1999, and Leikin, 2002), it was found that the peak latency of the P600 component elicited by sentences violating subject-verb agreement (with a singular NP as a subject) tended to be later in the left posterior region for the dyslexic group compared to the control group.

Combining the data of the two types of syntactic violations, the following picture emerges. Dyslexic subjects are fast in automatic detection of phrase-structure violations, whereas they tend to be slower in repairing subject-verb agreement violations. The more restricted distribution of the P600 furthermore indicates that less synchronously active neurons, or smaller populations of neurons are involved in the cognitive process of repair. How can these results be integrated in the data known from other studies? The N400 has been found to be present in dyslexic subjects, but to be delayed in comparison with control subjects (Brandeis et al., 1994; Helenius et al., 1999; 2002b). Helenius et al. (2002b) contribute this delay to a more general problem with speech analysis. They found the N100 response to speech sounds to be abnormally large in dyslexic individuals. The activation that underlies the N100 probably originates in the planum temporale and reflects phonetic-phonological processing. Helenius et al. (2002a) speculate on the basis of the observation that only speech sounds elicit an abnormal auditory N100 response in contrast with non-speech sounds, that neural populations in the planum temporale have failed to specialise adequately for speech processing. This in turn explains the phonological difficulties that are typical for dyslexic individuals.

Is it possible that the delay of the P600 component in the dyslexic adults is comparable to the delay of the N400? In other words, does pre-syntactic processing difficulty in the form of phonetic-phonological processing difficulty or delayed semantic processing, slow down the onset of syntactic repair? This may well be the case. Several studies have been carried out to investigate the dependency of syntactic repair on semantic information. Münte et al. (1993) used sentences in which the content words were replaced by pseudo-words (so-called jabberwocky sentences). When subject-verb agreement errors or phrase-structure
violations were presented in regular sentences, a classic P600 component was observed, which was not the case for the jabberwocky sentences, implying that the P600 is dependent upon the semantics of the sentence. Different data are found by Hahne & Jescheniak (2001) however. In their jabberwocky sentences containing phrase-structure violations (for instance, *das Fiehm wurde im gerottert), the P600 was present, just like the ELAN. The conflicting observations cannot be completely accounted for, but Hahne & Jescheniak (2001) suggest that the presence of the P600 in ‘semantically difficult or semantically empty’ sentences depends on the timing of violation detection. If a syntactic violation is detected before the signalling of lexical-semantic difficulties, a P600 is expected. However, when syntactic and semantic problems are processed in the same time frame, the P600 may be attenuated or absent. Thus, difficulties at multiple sources (syntactic and semantic level of processing) may hamper the repair process. These data show that syntactic repair, reflected by the P600, is to a certain extent dependent on semantic processing and integration. If a sentence lacks semantic meaning (in the case of jabberwocky sentences), the syntactic repair process is discarded when the syntactic violation has not been detected very early on (reflected by an ELAN component). Why some violations trigger such an early negativity in contrast with other violations remains to be investigated.

Going back to the ERP data of this study, it may be the case that the P600 tends to be delayed in the dyslexic individuals for the same reason as the N400: phonological processing difficulties slow down the access to the mental lexicon. Not only does this have implications for semantic processing, but also for repair of the syntactic structure of a sentence as semantic information also feeds this process. Delayed access to the semantic representations in the mental lexicon does not affect the detection of word category violations, as reflected by the ELAN, since that process does not depend on access to the semantic meaning of words (shown by the presence of the ELAN in jabberwocky sentences in Hahne & Jescheniak (2001)). Note that this explanation separates processing the syntactic information of a lexical representation (such as word category information and information about the structural context of the word (subcategorization)) from processing the lexical-semantic information.
6.5 Conclusions

The results from the present study show that the brain potentials of dyslexic students differed subtly from those of control subjects when they were processing sentences, even though the ability to judge sentences on their grammaticality was the same. An analysis of ERP latencies showed an interesting dichotomy: the ELAN peaked earlier in the dyslexic group, but the peak of the P600 tended to be later in the left hemisphere compared with the control subjects. The distribution of the ELAN was the same for both subject groups, whereas the distribution of the P600 showed subtle differences between the two groups. Furthermore, the dyslexic subjects did not show a syntactic repair process for ungrammatical sentences with a plural NP subject when they were compared with grammatical sentences containing a plural NP as a subject, nor for the phrase-structure violations. A tentative assumption based on these findings is that the first stage of syntactic parsing, mediated by a highly automatic process, is unaffected, but that brain activity involved in more strategic and controlled linguistic cognitive processes, underlying syntactic revision, is affected more by linguistic complexity and tends to be delayed in developmental dyslexia. This delay is likely to be the result of pre-syntactic processing difficulties which may stem from a functional disruption in the left posterior brain region of dyslexic subjects.
Appendix I.

Type 1 subject-verb agreement condition:

1. De aardige man zingt/zing een liedje
2. Het hertje Bambi loopt/loop een eindje
3. De vreemde jongen duwt/duw een meisje om
4. De kleine kleuter pakt/pak een snoepje
5. De witte hond blaft/blaf een tijdje
6. Mijn oude opa fietst/fiets een rondje
7. Mijn grote broer vangt/vang een rode bal
8. De vrolijke paashaas verstopt/verstop een eitje
9. De strenge meester schrijft/schrijf een zin op
10. De snelle dief steelt/steel een zak met geld
11. De kleine baby knoeit/knoei een beetje
12. De piraat begraaft/begraaf een grote schat
13. De snelle panter volgt/volg een tijger
14. De dikke kat miauwt/miauw in de tuin
15. De dikke kok bak/bak een eitje
16. De bruine hond ziet/zie een lekker bot
17. De aardige juffrouw tekent/teken een teddybeer
18. De brandweerman parkeert/parkeer een brandweerauto
19. De kleine jongen vouwt/vouw een papieren bootje
20. De grote man schaatst/schaats een tijdje
21. De vriendelijke juffrouw schilt/schil een appel
22. De gevaarlijke boef graaft/graaf een groot hol
23. De rijke koning slaapt/slaap in het bed
24. Mijn zus krijgt/krijg een mooie fiets
25. De lange jongen plaagt/plaag een meisje
26. Het vrolijke meisje zingt een wijsje
27. De dikke koe loopt een rondje
28. Het leuke meisje duwt een man om
29. Dagobert Duck pakt een dropje
30. De bruine hond blaft een keer
31. Het lieve meisje duwt een man om
32. Mickey Mouse vangt een grote bal
33. Winnie de Pooh verstoppt een potje honing
34. De nette mevrouw schrijft een lange brief
35. De dikke boef steelt een ketting
36. Het ondeugende zusje knoeit een beetje
37. Pluto de hond begraaft een dik bot
38. Het stoute meisje volgt een zwarte hond
39. Het kleine poesje miauwt in de keuken
40. Minnie Mouse bakt een appeltaart
41. Oom Dagobert ziet een zak met geld
42. Bert uit Sesamstraat tekent een appel
43. De deftige mevrouw parkeert een auto
44. Ernie uit Sesamstraat vouwt een hoedje
45. Donald Duck schaatst een rondje
46. Katrien Duck schilt een aardappel
47. Het kleine jongentje graaft een diepe kuil
48. De mooie prins slaapt in het paleis
49. Kermit de Kikker krijgt een sprookjesboek
50. Het kleine kindje plaagt een poesje

Fillers:

51. Ik zing in een koor
52. Ik wandel in het bos
53. Ik loop in de drukke stad
54. Ik ga naar het winkelcentrum
55. Ik koop een ijsje op het strand
56. Ik vraag een boterham aan mamma
57. Ik schilder een mooi huis
58. Ik teken een grote boom
59. Ik fiets heel hard naar school
60. Ik ren heel vaak een rondje
61. Ik voetbal elke woensdag
62. Ik tennis elke week
63. Ik vertel een spannend verhaal
64. Ik luister naar een sprookje
65. Ik zwaai naar mijn opa en oma
66. Ik roep naar mijn vriendje
67. Ik doe de brieven in de brievenbus
68. Ik vaar in een schip
69. Ik reken op school
70. Ik glijd van de glijbaan
71. Ik spring in het water
72. Ik rol door de kamer
73. Ik ruik aan de bloem
74. Ik bouw een toren
75. Ik lik aan een ijsje

Type 2 subject-verb agreement condition:

76. De blonde peuter kijkt/*kijken naar een pop
77. De lieve meid wast/*wassen een trui
78. De kleine kleuter gooit/*gooien een schoen
79. De aardige kapper knipt/*knippen het haar af
80. De jarige vrouw eet/*eten een taartje
81. De gevlekte hond bijt/*bijten de zwarte poes
82. De oude oma aait/*aaien het baby’tje
83. De grote man zaagt/*zagen een boom door
84. De aardige man kust/*kussen de vrouw
85. De aardige vrouw drinkt/*drinken een glas melk
86. De dikke koning rookt/*roken een pijp
87. De vrolijke kleuter trapt/*trappen tegen een bal
88. De vreemde heks krijgt/*krijgen een muis
89. De oude man opent/*openen een doos
90. De dikke oppasser lacht/*lachen om de aap
91. De gevaarlijke leeuw achtervolgt/*achtervolgen het aapje
92. De aardige man tekent/*tekenen een bloem
93. De dikke kok maakt/*maken een taart
94. De gestreepte poes eet/*eten een visje
95. De blonde vrouw leest/*lezen een boek
96. De oude meneer poetst/*poetsen zijn tanden
97. De grijze mus vliegt/*vliegen heel hoog
98. De oude vrouw breekt/*breken een kopje
99. De snelle sportman wint/*winnen een prijs
100. De aardige man bekijkt/*bekijken een schilderij
101. De rare man *kijken/kijkt naar een auto
102. De oude vrouw *wassen/wast een kopje
103. De blonde vrouw *gooien/gooit een bal
104. De meester *knippen/knipt het papier af
105. De aardige agent *eten/eet een ijsje
106. De gevaarlijke stier *bijten/bijt een koe
107. De lieve vrouw *aaien/aait het konijn
108. De grote timmerman *zagen/zaagt de plank door
109. De aardige man *kussen/kust het meisje
110. De dikke man *drinken/drinkt een glas sinasappelsap
111. De rijke prins*roken/rookt een sigaar
112. De grote koe *trappen/trapt tegen het hek
113. De lange vrouw *krijgen/krijgt een fiets
114. De jarige vrouw *openen/open een cadeautje
115. De vrolijke man *lachen/lacht om de clown
116. De zwarte poes *achtervolgen/achtervolgt een hondje
117. De dunne man *tekenen/tekent een banaan
118. De rare clown *maken/maakt een grapje
119. De kleine kleuter *eten/eet een snoepje
120. De lieve juffrouw *lezen/leest een boekje
121. De dunne man *poetsen/poetst zijn auto
122. De bruine vogel *vliegen/vliegt in de lucht
123. De onhandige man *breken/breekt een vaas
124. De snelle voetballer *winnen/wint een medaille
125. De stoere piraat *bekijken/bekijkt een boot

Type 3 subject-verb agreement condition:

126. De kleine kabouters lopen/*loopt in het bos
127. De groene knikkers vallen/*valt van de tafel af
128. De blonde peuters knoeien/*knoeit met het eten
129. De grote tijgers drinken/*drinkt het water
130. De lieve babies liggen/*ligt in de box
131. De kleine kleuters knutselen/*knutselt in de klas
132. De enge tovenaars kennen/*kent een heks
133. De tandenborstels liggen/*ligt in de badkamer
134. De zwarte vogels vliegen/*vliegt door de lucht
135. De vrolijke meesters zingen/*zingt een liedje
136. De oude ooms eten/*eet een stukje taart
137. De stoute jongens plagen/*plaagt het meisje
138. De dappere ridders rijden/*rijdt op hun paarden
139. De soeplepels liggen/*ligt in de bestekla
140. De aardige oppassers wandelen/*wandelt door het park
141. De gestreepte zebra’s volgen/*volgt de olifanten
142. De oude jagers jagen/*jaagt op de vogels
143. De kleine eekhoorns kruipen/*kruipt in de boom
144. De schuwe egels lopen/*loopt in de tuin
145. De dikke kikkers kwaken/*kwaakt in het water
146. De bruine ezels lopen/*loopt in het weiland
147. De tweelingbroers vechten/*vecht in de tuin
148. De grote cowboys achtervolgen/*achtervolgt een indiaan
149. De zwarte pantoffels liggen/*ligt onder mijn bed
150. De chauffeurs rijden/*rijdt een rondje

151. De kleine jongens *gooit/gooien een stok in het water
152. De vrolijke kabouter *woont/wonen naast een paddestoel
153. De tweelingbroers *koopt/kopen een zak snoep
154. De vriendelijke kappers *knipt/knippen mijn haren
155. De stoute jongens *verstopt/verstoppen de bal
156. De wilde tijgers *achtervolgt/achtervolgen de jongens
157. De leuke stickers *ligt/liggen in de kast
158. De bruine cavia’s *eet/eten een wortel
159. De melkbekers *valt/vallen op de grond
160. De aardige meesters *leest/lezen een zin voor
161. De snelle panters *rent/rennen door het oerwoud
162. De rode auto’s *rijdt/rijden door de straat
163. De groene kikkers *kwakt/kwaken in de vijver
164. De moedige ridders *woont/wonen in een kasteel
165. De stoere cowboys *rijdt/rijden op een paard
166. De aardige doktors *geeft/geven ons een prik
167. De aardige bakkers *verkoopt/verkopen veel brood
168. De langzame ezels *drinkt/drinken uit de rivier
169. De rare tovenaars *maakt/maken een drankje
170. De grappige clowns *valt/vallen over de schoenen
171. De rode knikkers *rolt/rollen over de grond
Sensitivity to syntactic violations: an ERP study

172. De lieve oppassers *woont/wonen vlakbij ons
173. De grote slagers *werkt/werken in een winkel
174. De aardige tantes *lacht/lachen om de grap
175. De snelle helikopters *vliegt/vliegen in de lucht

Phrase-structure condition:

176. Het kind heeft (*in de) gelachen
177. Het meisje heeft (*in de) gestoeid
178. De leeuw heeft (*in de) gevochten
179. De jongen heeft (*in de) gerolschaatst
180. Mijn oma heeft (*in de) gewandeld
181. Katrien Duck heeft (*in de) gedanst
182. Pluto heeft (*in de) geblaft
183. De kleuter heeft (*in de) gekleid
184. Het meisje heeft (*in de) geschommeld
185. Mijn tante heeft (*met de) gezwaaid
186. De man heeft (*in de) gevoetbald
187. De jongen heeft (*in de) gezwommen
188. Mijn neef heeft (*bij een) gelogeerd
189. Mijn moeder heeft (*in de) gefietst
190. De tovenaar heeft (*in de) gelopen
191. Kermit de Kikker heeft (*in de) geslapen
192. Het kind heeft (*in de) getennist
193. Mijn oom heeft (*in de) gevist
194. De vrouw heeft (*in de) gekampeerd
195. De meneer heeft (*in de) ontbeten
196. De jongen heeft (*in de) gespeeld
197. De vrouw heeft (*in de) gehuppeld
198. Mijn vriendin heeft (*in de) getelefoneerd
199. Willy Wortel heeft (*in de) geknutseld
200. De kleuter heeft (*in de) gehuild
201. Mijn oma heeft (*in de) gelachen
202. Mickey Mouse heeft (*in de) gestoeid
203. De gorilla heeft (*in de) gevochten
204. Nijntje Pluis heeft (*in de) gerolschaatst
205. De vrouw heeft (*in de) gewandeld
206. De koningin heeft (*in de) gedanst
207. Goofy heeft (*in de) geblaf
208. Mijn zusje heeft (*in de) gekleid
209. Het kind heeft (*in de) geshommeld
210. Het jongetje heeft (*in de) gezwaaide
211. De meneer heeft (*in de) gevoetbald
212. Mijn moeder heeft (*in de) gezwommen
213. Mijn oma heeft (*in de) gelogeerd
214. Mijn tante heeft (*in de) gefietst
215. De jongen heeft (*in de) gevist
216. De prins heeft (*in de) geslapen
217. Mijn tante heeft (*in de) getennist
218. De jongen heeft (*in de) gevist
219. Mijn vriendin heeft (*in de) gekampeerd
220. Mijn vriendje heeft (*in de) ontbeten
221. Het meisje heeft (*in de) gespeeld
222. Het kind heeft (*in de) gehuppeld
223. Mijn opa heeft (*in de) getelefoneerd
224. Mijn nichtje heeft (*in de) geknutseld
225. Het kind heeft (*in de) gehuild
Fillers phrase-structure condition:

226. De jongen heeft in de speeltuin gespeeld
227. De man heeft in de tuin gerookt
228. De vrouw heeft in de kamer genaaid
229. Het meisje heeft in het park gelezen
230. De man heeft in het bos gerend
231. De kok heeft in de keuken gekookt
232. De hond heeft in de grond gegraven
233. Het kind heeft in het restaurant gegeten
234. Het meisje heeft in de klas gerekend
235. Mijn opa heeft met mijn oma televisie gekeken
236. De jongen heeft in de auto overgegeven
237. Mijn broer heeft in de winkel betaald
238. Mijn zus heeft bij een vriendin huiswerk gemaakt
239. De jongen heeft op het schoolplein geknikkerd
240. De prinses heeft in het bos gezeten
241. De vrouw heeft in de keuken afgewassen
242. De vrouw heeft in de tuin gebreid
243. Het meisje heeft in het klaslokaal geschilderd
244. Mijn neef heeft in de tuin geharkt
245. De ober heeft in het café gewerkt
246. Het kind heeft in de tuin gehinkeld
247. De meester heeft in de klas voorgelezen
248. De poes heeft in de slaapkamer gemiauwd
249. Mijn neefje heeft in de dierentuin gelachen
250. De baby heeft in de kamer gekropen