Word-recognition processes in normal and dyslexic readers

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Chapter 2

The use of sublexical clusters in normal and dyslexic readers

Abstract

The current study examined the use of sublexical clusters in normal and dyslexic readers. We focused primarily on onset consonantal clusters, but the use of rimes and digraphs was also considered. A segmentation paradigm, the separation of two adjacent letters in a word by a nonletter symbol, was used. We hypothesized that the effect of this distortion on reading would be larger if two adjacent letters functioned as a cluster. In the first study, naming and lexical decision tasks were administered to 24 normal reading and 24 dyslexic grade-4 children. In a second study, the same tasks were administered to 24 skilled adult readers. The results did not support the use of consonantal onsets and rimes during reading. However, we did find that digraphs were used, because their distortion had a relatively large effect on reading speed. This effect was similar in normal and dyslexic readers.

2.1 Introduction

Sublexical clusters are units that are larger than one letter, but smaller than a word. They pertain to any combination of letters including digraphs, consonant clusters, coda, and rimes. In the study presented here, we examined whether such clusters are acquired during reading acquisition. This issue is of both theoretical and practical importance.

Current models of skilled reading differ in the extent and ways in which they represent sublexical clusters. In several connectionist models, sublexical clusters have been explicitly built into the model, or are an emergent property of the (statistical) learning of a distributed network (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996). In contrast, in the Dual Route Cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) the decoding of a letter string is by default based on the input of the separate letters of the presented letter string. The DRC model features context sensitive rules when more letters are needed to determine the specific pronunciation, for example, in case the letter string contains an inconsistency like a digraph. In this case, the letters are temporarily treated as a unit, but not stored as a sublexical cluster. When the DRC model later encounters a (pseudo)word containing the same letter combination, it will reactivate the context sensitive rules, and will not directly recognize the letters as unit. In addition, the DRC model will only process more letters at once when an inconsistency has to be resolved, whereas connectionist models also learn sublexical clusters with consistent pronunciations.

Several developmental theories of reading also assume that children learn to use sublexical clusters. In the last phase of Ehri’s phase theory of reading acquisition, the so-called consolidated alphabetic phase, associations are established between multiletter units and their corresponding phonological segments in spoken words (Ehri, 1992; 1998). According to the Psycholinguistic Grain Size Theory (Ziegler & Goswami, 2005) on the other hand, the emergence of sublexical units is not linked to the phase of reading acquisition, but is assumed to depend on the consistency of the grapheme to phoneme mappings of the orthography. Accordingly, in English, for example, with its numerous inconsistent grapheme-to-phoneme associations, readers will use sublexical units, whereas in more consistent orthographies, such as Dutch, Greek or German, they will not.

Several interventions, designed to improve the reading fluency of beginning and dyslexic reader, have explicitly focused on the use of sublexical clusters (Dassmaal, Klapwijk, & van der Leij, 1996; van Daal, Reitsma, & van der Leij, 1994). The general idea behind these interventions is that the use of sublexical units by dyslexic readers will increase their reading speed of both familiar and novel words. Unfortunately, however, the effects of such interventions seem to be small. One explanation for these findings might be that the correct method to stimulate the use of sublexical clusters has not yet been found. Up until now, researchers have
mainly stimulated the use of sublexical clusters by visual manipulations within the word, such as by highlighting the target clusters with a color or by printing clusters in bold letter type (Levy, 2001; Thaler, Ebner, Wimmer, & Landerl, 2004), or have enhanced the saliency of target clusters by grouping words with the same cluster in word family lists (Levy, 2001; Reitsma, 1988). However, another explanation might be that the assumption that skilled readers use sublexical clusters, and dyslexic readers do not is simply wrong. The latter possibility is the focus of our study. More specifically, we will examine whether normal reading and dyslexic children, learning to read in Dutch, use sublexical clusters during reading.

As evident from the former description, both models of skilled reading and developmental theories of reading make different predictions about the use of sublexical clusters by normal readers. This is also the case for dyslexic readers. At first sight, the predictions for dyslexic readers might be further complicated by the fact that dyslexics form a heterogeneous group. For example, based on the DRC model, a distinction has been made between phonological and surface dyslexics (Castles & Coltheart, 1993). However, the relevance of this distinction for children learning to read a regular orthography is not yet clear and might be difficult to support as irregular words are, by definition, rare and pseudoword reading is fairly accurate (e.g., de Jong & van der Leij, 2003). Indeed, especially in relatively transparent alphabetic orthographies, impairments in reading fluency, and not accuracy, have been regarded as an important characteristic of dyslexia (de Jong & van der Leij, 2003; Landerl, Wimmer, & Frith, 1997; Torgesen, 2005). Impairments in reading speed have been associated with a lack of both sublexical and lexical knowledge. This is also revealed by larger effects of word length in dyslexic readers which are thought to reflect an abundant use of a serial letter-by-letter phonological-recoding strategy (Martens & de Jong, 2006; Zoccolotti et al., 2005). Therefore, our predictions for the Dutch dyslexic readers were straightforward. From the DRC model (Coltheart et al., 2001) and the Psycholinguistic Grain Size Theory (Ziegler & Goswami, 2005) we did not expect differences between normal reading and dyslexic children in the use of sublexical clusters. Because, according to these models, such clusters are not learned or represented at all. On the other hand, connectionist models (Harm & Seidenberg, 1999) and Ehri’s (1992, 1998) phase theory predict a difference between normal reading and dyslexic children. For example, according to Harm and Seidenberg’s model dyslexic children are less able to use sublexical clusters in reading. Their impaired model (modeling dyslexic reading) did not develop overlapping representations for words with the same letter clusters, whereas an unimpaired model (modeling normal reading) had a clear preference for the development of this kind of representations. It is interesting to note that Harm and Seidenberg used different methods to create impairments in their model in order to simulate phonological and surface dyslexia. However, for both simulations the result was the same, namely less use of sublexical clusters.
In earlier studies, a visual segmentation paradigm has been regularly employed to demonstrate the use of sublexical clusters in skilled adult readers (Bowey, 1996; Martensen, Maris, & Dijkstra, 2003). In this paradigm, the written form of a word is distorted by inserting one or more nonletter symbols between two letters (e.g., *s*//top), or by presenting two adjacent letters in a different case (case alternation: *s*TOP). The straightforward prediction is that the effect of this visual distortion on reading is larger if during reading these two letters are used as a sublexical cluster than when they are not. By using the segmentation paradigm, some studies have found evidence for the rime as a functional unit in skilled adult readers in lexical decision and anagram tasks (Treiman & Chafetz, 1987; van den Bosch, 1991). However, this finding has not always been replicated in naming experiments (Bowey, 1996; van den Bosch, 1991).

For a number of reasons, we focused in this study primarily on consonantal onset clusters. First, consonantal onset clusters are very frequent in Germanic languages. For example, approximately 35% of the Dutch monosyllabic words in the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993) start with a consonant cluster. However, only 11 different consonantal onset clusters are found in about 55% of these words. Thus, from a statistical point of view and given the finding that children are also sensitive to the statistical regularities of an orthography (Pacton, Perruchet, Fayol, & Cleeremans, 2001), it can be expected that these consonantal onset clusters will be formed. Furthermore, the complex linguistic structure of consonant clusters has been shown to be especially difficult for dyslexic children (Bruck & Treiman, 1990). Finally, as said, in transparent orthographies young readers and dyslexic children often are assumed to use a serial recoding strategy. With such a strategy the consonant onset cluster is the first unit a reader encounters while reading a word.

To date, only a few studies have focused on the use of consonantal onset clusters. Levitt, Healy, and Fendrich (1991) did not find an indication for the use of consonantal onset clusters by adult readers in naming and lexical decision. Using another segmentation paradigm, Bowey (1996) found evidence for the use of consonantal onset clusters in a first study, but could not replicate this finding in a subsequent study. In the only study that we know of in which the use of consonantal onset clusters in children was examined, van den Bosch (1991) did not find a difference for first graders between the reading of consonant-consonant-vowel-consonant (CCVC) and CVCC pseudowords that were segmented either within or outside the consonant cluster. However, these children only had 8 months of reading instruction, which might not have been sufficient to acquire sublexical clusters (Ehri, 1992, 1998). In sum, the evidence for the use of onset consonant clusters as functional units in reading seems inconclusive. Moreover, studies about differences in the use of consonantal onset clusters by normal and dyslexic children are scarce, despite the fact that several intervention studies have aimed to enhance their use.
In our study, we administered naming and lexical decision tasks to normal and dyslexic grade-4 children (Study 1). In one condition, the consonantal onset cluster was segmented by inserting a hash within the cluster (e.g., s#top). In another condition the segmentation was between onset and rime (e.g., st#op). All consonantal onset clusters were consistent. If these clusters are used in reading, like the connectionist models and Ehri’s phase model predict, the segmentation of the onset cluster should lead to a relatively larger decrease in reading speed than the segmentation between onset and rime in which the onset cluster remains intact.

However, an alternative interpretation of a larger effect of the segmentation of a consonant onset cluster than the segmentation between onset and rime is that the position of the former segmentation (s#top) is more in the beginning of the word than the position of the latter (st#op). To examine this alternative interpretation, we included CVCC words and pseudowords. These words were segmented in the same positions as the CCVC (pseudo)words—that is, after the first and the second letter—but in CVCC structures these segmentations were between onset and rime (e.g., t#est) and within the rime (te#st), respectively. A comparison of the C#CVC and the C#VCC condition will rule out the possibility that a difference between the C#CVC and the CC#VC condition is merely a positional effect. An additional advantage of the inclusion of CVCC (pseudo)words was that the use of the rime cluster could also be pursued.

Given the viability of the hypothesis that consonantal onset clusters are not used as functional units in reading, we ran the risk to obtain a null-result. For a better interpretation of such a result, we added two features to our study. First, we included a naming task with words with both consonantal onset clusters and vowel digraphs. In contrast to onset clusters, both letters of a digraph map onto one phoneme and, consequently, both letters need to be considered to establish the correct mapping. If the segmentation paradigm is effective, then a segmentation of a vowel digraph within a word (e.g., blo#em [flower]) should lead to a larger decrease in naming speed as compared to the segmentation of the consonantal onset and rime. Martensen et al. (2003) already demonstrated this effect in Dutch adult readers. Finally, we administered the naming and lexical decision tasks to adult readers (Study 2) to rule out the possibility that even the normal reading children were not yet proficient enough to use the consonantal onset clusters as a functional unit in reading.

2.2 Study 1: Children

The first study that we conducted, focuses on the use of sublexical clusters in normal reading and dyslexic children. Below, we describe the method, present the results and discuss the outcome.
2.2.1 Method

Participants

Twenty-four dyslexic grade-4 children (11 boys, 13 girls) and 24 normal reading children (11 boys, 13 girls) participated in the study. All children attended regular education and had normal, or corrected to normal, vision. The characteristics of the two groups are presented in Table 2.1.

The dyslexic and normal reading children were selected from a group of 498 grade-4 children of 15 different schools in the area of Purmerend (The Netherlands). Normal word reading ability was defined to range from 3 months below to 3 months above the average reading level of grade-4 students. The dyslexic children had a reading lag of at least 1.5 years. The dyslexic children were individually matched with the normal reading group on receptive vocabulary, nonverbal intelligence, age, and gender.

Table 2.1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dyslexic</th>
<th></th>
<th>Normal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.9</td>
<td>0.4</td>
<td>9.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Reading level (standard score)</td>
<td>62.8</td>
<td>5.1</td>
<td>99.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Vocabulary score</td>
<td>45.3</td>
<td>3.2</td>
<td>45.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Nonverbal reasoning score</td>
<td>36.4</td>
<td>7.4</td>
<td>37.0</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Word reading ability was assessed with the Dutch One-minute test (Brus & Voeten, 1995), which was administered individually. This test is commonly used to determine the reading level of children in Dutch primary schools. The test consists of 116 unrelated words of increasing length and difficulty, and has got an A and a B version. All children read both versions of the test. The score was the number of words that were read correctly. On the basis of this raw score a standardized score was computed ($M = 100$, $SD = 15$). The final score was the average of the standard scores of the two versions.

Receptive vocabulary of the children was measured with the subtest Vocabulary of the RAKIT, a Dutch intelligence test battery for children (Bleichrodt, Drenth, Zaal, & Resing, 1987). The test consists of 60 words of increasing difficulty. For each word, the children had to choose the corresponding picture out of four alternatives. When a child made four errors in a row, the administration of the test was stopped. The score was the number of correct answers. Finally, nonverbal reasoning was assessed with the Raven Standard Progressive Matrices (Raven, Court, & Raven, 1986). The Raven consists of 60 items. On each item, the children had to choose a pattern from a set of answer options to complete a series of patterns. The score was the number of correct answers.
Tasks

**CCVC/ CVCC Naming Task**  We identified high-frequency consonant clusters with a bigram frequency list, based on a corpus of youth literature (Bakker, 1990; Staphorsius, Krom, & de Geus, 1988). Eleven different consonantal onset clusters and 10 different consonantal coda clusters were selected that were both frequent in general and frequent for the onset and coda positions, respectively. Next, we selected 30 high-frequent regular CCVC and 30 high-frequent regular CVCC words starting (e.g., stop), or ending (e.g., test), with the target onset and coda clusters from the CELEX database (Baayen et al., 1993).

Pseudowords were derived from the words by exchanging the first two letters with the first two letters of another word. This procedure was done separately for the CCVC and the CVCC words. As a result, the naming task consisted of 120 items. The word and pseudoword sets are presented in Appendix A.1.

We chose to insert a hash (#) to invoke the segmentation (C#CVC). The hash sign is a new stimulus for most children; it covers a relatively large body of space (thus the segmentation effect is probably enhanced) and cannot be confused with other letters or signs. (Pseudo)words were administered in three segmentation conditions: (a) segmentation after the first letter; (b) segmentation after the second letter; or (c) no segmentation. Notice that the two segmentation conditions had different implications for the CCVC and CVCC items. In a CCVC word, segmentation after the first letter distorted the consonantal onset cluster. In contrast, in a CVCC word it did not distort a cluster, because it was between the onset and the rime. In a CVCC word, segmentation after the second letter distorted the rime cluster. However, such a distortion in a CCVC word leaves all clusters intact.

Each word and pseudoword occurred in every segmentation condition. As a result, voice key differences between conditions were completely controlled for (Kessler, Treiman, & Mullennix, 2002). However, every child read each word and pseudoword only once. As a result, there were three different versions of the word and pseudoword reading tasks. The children were randomly assigned to one of the three versions.

The words and pseudowords were administered in two separate blocks, and the words and pseudowords within a block were presented in random order. Half of the children started with the word block, whereas the other half first read the pseudoword block.

**Vowel-Digraph Naming Task**  We used the same procedure to identify 15 high-frequency onset clusters (general and position specific) as for the CCVC words. After this, we selected 40 high-frequent CCVVC words starting with the target onsets (e.g., bloem [flower]) from the CELEX database (Baayen et al., 1993). Only words with heterogeneous vowel digraph clusters (e.g., oe, ui, eu) were selected. The word set is presented in Appendix A.2. The vowel-digraph naming task did
not contain pseudowords.

The words were administered in four different conditions: (a) segmentation with consonant cluster distorted ($C\#CVVC$); (b) segmentation with vowel digraph distorted ($CCV\#VC$); (c) segmentation with rime distorted ($CCVV\#C$); or (d) no segmentation ($#CCVVC$).

On this task all children also read each word once, although each word occurred in every segmentation condition. As a consequence, four different versions of the word reading task were constructed. The children were randomly assigned to one of the four versions of the task. The words in each version were presented in random order.

**CCVC/ CVCC Lexical Decision Task**  
The word and pseudoword sets of the CCVC/ CVCC naming task were used to develop a parallel lexical decision task. The items were mixed and divided into two blocks of 60 trials. Words and pseudowords, and CCVC and CVCC structure items, were evenly distributed between the blocks.

The words and pseudowords were administered in the same three conditions as in the CCVC/ CVCC naming task: (a) distortion after the first letter, (b) distortion after the second letter, or (c) no distortion. The children were randomly assigned to one of the three versions of the lexical decision task. The words and pseudowords were randomly presented within the blocks.

**Procedure and Apparatus**

The tasks were administered during school time in two individual sessions of 30 minutes. The CCVC/ CVCC naming task (words and pseudowords) was administered during the first session. To avoid priming effects because of the use of identical word sets, the lexical decision task and the vowel digraph naming task were administered 3 weeks after the CCVC/ CVCC naming task. The children were told that there would be “special signs” inserted into the words, and were instructed to ignore the signs and read (naming tasks) or respond to (lexical decision task) the words as quickly as possible, without making errors. Each block was preceded by 10 practice trials. The words and pseudowords were presented in the middle of a 14.1-inch XGA LCD screen of a D600 Pentium-M 1.3-GHz computer. The words were printed in 46-point lowercase, black Arial font on a white background. A fixation point (+) was projected in the middle of the screen, and 750 ms later a (pseudo)word appeared. For the naming tasks, the voice key registered latencies and the test assistant recorded accuracy. The latencies were defined as the time between the appearance of the word or pseudoword on the screen and the onset of the voice key. The (pseudo)words disappeared as soon as the voice key was triggered. For the lexical decision task, the latencies were defined as the time between the appearance of a word or pseudoword on the screen...
and the moment the child pushed a button. The M key on the keyboard was covered by a green sticker, and the C key was covered by a red sticker. The children were instructed to push the green button when they read a word, and the red button when they read a pseudoword. The results on the naming and on the lexical decision tasks are presented in separate sections. First, however, we give a description of the planned statistical analyses.

2.2.2 Results

Scoring and Statistical Analyses

For each child, a mean latency score was computed for each word type by segmentation condition. Mean latency scores were calculated over correct trials only. With some exceptions (less than 3%), mean latency scores were based on at least 5 of the total of 10 trials in a condition.

Error scores and mean latency scores for each word type (CCVC, CVCC, and CCVVC) were subjected to a multivariate analysis of variance (MANOVA) for repeated measures, with reading group (dyslexic or normal) as a between-subjects factor, and position of segmentation and lexicality (word or pseudoword) as within-subjects factors. In each case, two analyses were conducted; one across participants (collapsing over items), and another across items (collapsing over participants). The outcomes for both types of analysis were in generally similar. For brevity, we only report the outcomes across participants. Moreover, when experiments are designed in such a way that each stimulus appears in each condition, the proper $F$ test is the participant analysis (Raaijmakers, Schrijnemakers, & Gremmen, 1999).

To test the hypothesis that, compared to between cluster segmentation, within cluster segmentation has a larger effect on latencies and possibly on errors, several contrasts were specified on the position of segmentation factor. The first contrast concerned the effect of segmentation as such, and is further denoted as the Segmentation contrast. With this contrast, the conditions in which the hash was placed within the word were compared with the no segmentation condition (i.e., a hash before the word). The other, and more important, contrasts were specified to compare the various segmentation positions within a (pseudo)word. These contrasts will be referred to as Cluster contrasts. The particular Cluster contrasts differed between the word types. For both contrasts (Segmentation and Cluster), a significant main effect indicated a mean score difference between the conditions that were compared, whereas a significant Contrast $\times$ Reading Group interaction implied that the magnitude of this difference varied between the two reading groups.

A major hypothesis of this study concerned the Reading Group $\times$ Cluster interaction. However, if larger mean latency differences are found between the two reading groups—which can be expected—the interpretation of the Reading
Group by Cluster interaction is not straightforward. In this case, a significant interaction might merely reflect a proportional difference between the groups in the effect of the other factor, cluster, segmentation, or lexicality. This means that a differential increase between the groups from one condition to another is just a function of the difference that was observed in the first condition. However, an absolute interaction effect implies that the increase of naming latency is stronger for one of the groups, irrespective of the difference that was already found in the first condition.

To check whether a significant interaction reflects a proportional effect, we subjected the scores to a logarithmic transformation (Levine, 1993; van der Sluis, de Jong, & van der Leij, 2004) and performed the MANOVA on the transformed scores. If the interaction effect disappears in the analysis on the transformed scores, then the original interaction effect is proportional. However, if the interaction effect remains, it is safe to conclude that the reading groups are differently affected by the experimental manipulation, cluster, segmentation, or lexicality.

**Naming**

The percentage of invalid latencies that were attributable to premature responses, voice key errors, and outliers was 6.4% for CCVC (pseudo)words and 7.2% for CVCC (pseudo)words. For the CCVCC words, this percentage was 10%. The results are presented separately for each word type.

**CCVC Words and Pseudowords** For each condition, the mean error percentages and mean latency scores for both reading groups are presented in the upper part of Table 2.2.

**Errors.** The mean error percentages for the normal readers were well below 10%. For the dyslexic children, the mean percentages of errors on words were around 10%, whereas for the reading of pseudowords the mean percentages were about 20%. The analysis of the mean error percentages was restricted to the pseudowords, because of floor effects for the words. For pseudoword naming, the mean error percentage of the dyslexic children was higher than the mean error percentage of the normal readers, \( F(1, 46) = 9.10, p < .01, \eta^2_p = .17 \). No other effects were significant.

**Latencies.** There were main effects for reading group, \( F(1, 46) = 67.11, p < .001, \eta^2_p = .59 \); lexicality, \( F(1, 46) = 51.11, p < .001, \eta^2_p = .53 \); and position of segmentation, \( F(2, 45) = 13.79, p < .001, \eta^2_p = .38 \). These main effects were qualified by significant Lexicality \( \times \) Reading Group interaction, \( F(1, 46) = 31.92, p < .001, \eta^2_p = .41 \); and Position of Segmentation \( \times \) Reading Group interaction, \( F(2, 45) = 3.76, p < .05, \eta^2_p = .14 \). The Lexicality \( \times \) Reading Group interaction was not proportional, as it remained significant after a logarithmic transformation of the latency scores, \( F(1, 45) = 20.76, p < .001, \eta^2_p = .31 \). No other effects were
2.2. STUDY 1: CHILDREN

Table 2.2

<table>
<thead>
<tr>
<th>Item type</th>
<th>Words</th>
<th>Pseudowords</th>
</tr>
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<tbody>
<tr>
<td>CCVC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#CCVC</td>
<td>1087 (344)</td>
<td>1696 (557)</td>
</tr>
<tr>
<td>C#CVC</td>
<td>1283 (365)</td>
<td>1985 (643)</td>
</tr>
<tr>
<td>CC#VC</td>
<td>1279 (325)</td>
<td>1926 (724)</td>
</tr>
<tr>
<td>CCVC Errors (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#CCVC</td>
<td>7.31 (8.89)</td>
<td>16.00 (9.43)</td>
</tr>
<tr>
<td>C#CVC</td>
<td>7.47 (10.23)</td>
<td>21.93 (16.96)</td>
</tr>
<tr>
<td>CC#VC</td>
<td>11.08 (11.17)</td>
<td>17.13 (13.08)</td>
</tr>
<tr>
<td>CVCC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#CVCC</td>
<td>1181 (360)</td>
<td>1799 (594)</td>
</tr>
<tr>
<td>C#VCC</td>
<td>1309 (402)</td>
<td>2153 (758)</td>
</tr>
<tr>
<td>CV#CC</td>
<td>1370 (376)</td>
<td>2107 (681)</td>
</tr>
<tr>
<td>CVCC Errors (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#CVCC</td>
<td>15.16 (12.87)</td>
<td>21.05 (12.46)</td>
</tr>
<tr>
<td>C#VCC</td>
<td>8.56 (9.12)</td>
<td>22.61 (20.73)</td>
</tr>
<tr>
<td>CV#CC</td>
<td>11.79 (11.43)</td>
<td>21.47 (20.96)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

significant. Latency scores were larger for dyslexic than for normal readers, and larger for pseudowords than for words, but the difference between the mean word naming latency score and the mean pseudoword naming latency score was larger for the dyslexic than for the normal reading children.

The position of segmentation effects were examined with follow-up contrasts. The Segmentation contrast, comparing the no segmentation condition with the two within-word segmentation conditions, $F(1, 46) = 22.70, p < .001, \eta^2_p = .33$; and Segmentation × Reading Group interaction, $F(1, 46) = 5.05, p < .05, \eta^2_p = .10$, were significant. However, the interaction effect was proportionally similar for dyslexic and normal reading children. The Cluster contrast, comparing segmentation within the consonantal onset cluster and the condition with segmentation between onset and rime, was not significant, and neither was the Cluster × Reading Group interaction.

In sum, children of both groups were faster in naming intact than segmented CCVC (pseudo)words. However, the mean naming latencies for (pseudo)words with a segmented consonant onset cluster (C#CVC) did not differ from the mean latencies for (pseudo)words segmented on the onset-rime boundary (CC#VC).

CVCC Words and Pseudowords For each condition, the mean error percentages and mean latency scores for both groups are given in the lower part of Table 2.2. Errors. As found for the naming of the CCVC words and pseudowords, the
mean error percentage for the normal readers was low (less than 9%), and in several conditions floor effects were observed. Therefore, the MANOVA on the mean error percentage was restricted to the pseudowords. The dyslexic children made significantly more errors in pseudoword reading than the normal reading children, $F(1, 46) = 74.97, p < .001, \eta^2_p = .62$. No other effects were significant.

**Latencies.** There were main effects for reading group, $F(1, 46) = 85.42, p < .001, \eta^2_p = .65$; lexicality, $F(1, 46) = 46.84, p < .001, \eta^2_p = .51$; and position of segmentation, $F(2, 45) = 16.83, p < .001, \eta^2_p = .43$. These main effects were qualified by a significant Lexicality $\times$ Reading Group interaction, $F(1, 46) = 33.91, p < .001, \eta^2_p = .42$. This interaction was not proportional, as it remained significant in the analysis of the logarithmically transformed scores, $F(1, 46) = 23.17, p < .001, \eta^2_p = .34$. No other effects were significant. Latency scores were larger for dyslexic than for normal readers, and larger for pseudowords than for words, but the difference between the mean word and pseudoword latency score was larger for the dyslexic than for the normal readers.

The position of segmentation effect was examined with follow-up contrasts. The Segmentation contrast was significant, $F(1, 46) = 34.19, p < .001, \eta^2_p = .43$, whereas the main effect for Cluster (rime) was not.

In sum, children of both groups were faster in naming intact than segmented CVCC (pseudo)words. However, the mean naming latencies for (pseudo)words with a segmented rime cluster (CV#CC) did not differ from the mean latencies for segmentation on the onset-rime boundary (C#VCC).

**CCVVC Words** The mean error percentages and mean latency scores for the two reading groups in the various segmentation conditions are presented in Table 2.3. The main interest of this naming task concerned a comparison between the segmentation of a cluster and the segmentation of a vowel digraph. Therefore, in the analyses reported next, a Digraph contrast was specified to compare the consonantal onset cluster segmentation (located before the vowel digraph) plus the rime segmentation (located after the vowel digraph) with the segmentation of the vowel digraph.

**Errors.** The statistical analysis of the mean error percentage was restricted to the dyslexic children because of floor effects. The main effect of position of segmentation was significant, $F(3, 21) = 3.19, p < .05, \eta^2_p = .31$. Follow-up contrasts were specified to examine the nature of this effect.

The Segmentation contrast was significant, $F(1, 23) = 6.75, p < .05, \eta^2_p = .23$. Dyslexic children made more errors in distorted than in intact words. The Digraph contrast approached significance, $F(1, 23) = 2.99, p = .097, \eta^2_p = .16$. There was a trend for the dyslexic children to make more errors in the vowel digraph distortion condition than in the consonantal onset cluster distorted and rime distorted conditions. Finally, the Cluster Type contrast was not significant. For the dyslexic
2.2. STUDY 1: CHILDREN

Table 2.3
Study 1: Mean latency scores and mean error percentages on the CCVVC words in the different segmentation positions of the digraph-naming task for dyslexic and normal reading children.

<table>
<thead>
<tr>
<th>Reading group</th>
<th>Item type</th>
<th>Latencies</th>
<th>Errors (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>#CCVVC</td>
<td>773 (391)</td>
<td>0.83 (2.82)</td>
</tr>
<tr>
<td></td>
<td>C#CVVC</td>
<td>776 (302)</td>
<td>1.40 (3.80)</td>
</tr>
<tr>
<td></td>
<td>CCV#VC</td>
<td>965 (492)</td>
<td>3.77 (6.38)</td>
</tr>
<tr>
<td></td>
<td>CCVV#C</td>
<td>819 (391)</td>
<td>2.03 (4.63)</td>
</tr>
<tr>
<td>Dyslexic</td>
<td>#CCVVC</td>
<td>1491 (442)</td>
<td>3.00 (6.48)</td>
</tr>
<tr>
<td></td>
<td>C#CVVC</td>
<td>1741 (520)</td>
<td>6.20 (9.11)</td>
</tr>
<tr>
<td></td>
<td>CCV#VC</td>
<td>2183 (645)</td>
<td>13.51 (15.30)</td>
</tr>
<tr>
<td></td>
<td>CCVV#C</td>
<td>1729 (512)</td>
<td>9.35 (10.68)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

...children, the amount of errors in the distorted consonantal onset did not differ from the amount of errors in the distorted rime cluster condition.

**Latencies.** Significant effects were found for reading group, $F (1, 46) = 59.62$, $p < .001$, $\eta^2_p = .56$, and position of segmentation, $F (3, 44) = 22.77$, $p < .001$, $\eta^2_p = .61$. These main effects were qualified by a significant Position of Segmentation $\times$ Reading Group interaction, $F (3, 44) = 9.25$, $p < .001$, $\eta^2_p = .39$. No other results were significant.

The position of segmentation effects were examined with follow-up contrasts. The Segmentation contrast was significant, $F (1, 46) = 13.67$, $p = .01$, $\eta^2_p = .23$. This effect was qualified by a significant Segmentation $\times$ Reading Group interaction, $F (1, 46) = 9.06$, $p < .01$, $\eta^2_p = .16$, and this interaction was not a proportional effect, $F (1, 46) = 6.01$, $p < .05$, $\eta^2_p = .12$. The Digraph contrast was also significant, $F (1, 46) = 43.87$, $p < .001$, $\eta^2_p = .49$. In addition, we found a significant Digraph $\times$ Reading Group interaction for participant data, $F (1, 46) = 9.13$, $p < .01$, $\eta^2_p = .17$. However, this interaction effect disappeared when a logarithmic transformation of the latency scores were applied, indicating that it reflected a proportional effect.

In sum, it was found that the mean latency score of the dyslexic children was larger than the mean latency score of the normal reading children, and that this difference was larger for segmented than for intact words. For both groups, the mean latency score was larger when the distortion was within the vowel digraph than when the distortion was outside the vowel digraph. Finally the increase in the naming latency in reaction to segmentation of a consonant onset cluster or a rime did not differ between normal reading and dyslexic children.

**Lexical Decision**

We noticed that some children had high error rates. To verify whether this was because these children were using a guessing strategy instead of making well-
considered lexical decisions, we defined the critical value for the guessing chance per lexicality (60 words, 60 pseudowords). To correct for the chance of making a Type I error, we used the Bonferroni correction to calculate the appropriate level of significance ($\alpha/n = 0.05/48 = .001$). The critical value for this chance was 43. This means that a child was considered as “not guessing” when it responded correctly to at least 43 of the 60 words or pseudowords. Four children (two normal readers and two dyslexic children) were excluded from the analyses. The removal of these participants did not influence the matching of the two reading groups.

For the remaining children, the percentage of invalid latencies that were caused by premature responses and outliers was 1.5% for CCVC and 0.9% for CVCC (pseudo)words. The responses to one CCVC structure word (blos [blush]) were excluded from the analyses, because the majority of the children categorized this word as a pseudoword. The results are presented separately for each word type.

**CCVC Words and Pseudowords** For each condition, the mean error percentages and mean latency scores for both reading groups are presented in the upper part of Table 2.4. An error in the word condition indicates that a word was identified as a pseudoword, and an error in the pseudoword condition indicates the opposite.

**Errors.** Overall, the mean error percentages ranged from 8% to 15%. The main effect for lexicality was significant, $F(1, 42) = 5.24, p < .05, \eta^2_p = .11$. The children made more errors on words than on pseudowords. The Position of Segmentation $\times$ Group interaction effect was marginally significant, $F(2, 41) = 3.17, p = .053, \eta^2_p = .13$. No other effects were found. Follow-up contrasts were specified to examine the nature of this interaction effect. We found that the Segmentation $\times$ Reading Group interaction was also marginally significant, $F(1, 42) = 3.82, p = .057, \eta^2_p = .083$. The dyslexic children tended to make more errors on the segmented (pseudo)words than the normal reading children.

**Latencies.** There were main effects for reading group, $F(1, 42) = 113.17, p < .001, \eta^2_p = .73$; lexicality, $F(1, 42) = 133.57, p < .001, \eta^2_p = .76$; and position of segmentation, $F(2, 41) = 27.90, p < .001, \eta^2_p = .58$. These main effects were qualified by a significant Lexicality $\times$ Reading Group, $F(1, 42) = 32.35, p < .001, \eta^2_p = .44$, and a marginally significant Position of Segmentation $\times$ Reading Group interaction effect, $F(2, 41) = 3.01, p = .060, \eta^2_p = .13$. The Lexicality $\times$ Reading Group interaction was not proportional, $F(1, 42) = 9.04, p < .01, \eta^2_p = .18$. However, the Position of Segmentation $\times$ Reading Group interaction effect lost significance when the logarithmically transformed latency scores were used. No other effects were significant. Latency scores were larger for dyslexic than for normal readers, and larger for pseudowords than for words, but the difference between the mean word decision latency and the mean pseudoword decision latency was larger for the dyslexic than for the normal readers.

The position of segmentation effect was examined with follow-up contrasts.
2.2. STUDY 1: CHILDREN

Table 2.4
Study 1: Mean latency scores and mean error percentages on the two word structures in the different segmentation positions of the lexical decision task for dyslexic and normal readers.

<table>
<thead>
<tr>
<th>Item type</th>
<th>CCVC</th>
<th>Dyslexics</th>
<th>Normal</th>
<th>Pseudowords</th>
<th>Dyslexics</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>#CCVC</td>
<td>1698 (403)</td>
<td>940 (190)</td>
<td>2598 (438)</td>
<td>1261 (373)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C#CVC</td>
<td>1967 (342)</td>
<td>1103 (289)</td>
<td>2979 (731)</td>
<td>1371 (521)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC#VC</td>
<td>1994 (477)</td>
<td>1120 (366)</td>
<td>2700 (549)</td>
<td>1422 (505)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCVC Errors (%)</td>
<td>8.18 (7.95)</td>
<td>13.59 (9.68)</td>
<td>9.09 (11.92)</td>
<td>7.73 (9.73)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C#CVC Errors (%)</td>
<td>15.76 (13.11)</td>
<td>14.95 (13.56)</td>
<td>7.37 (9.73)</td>
<td>8.38 (8.71)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC#VC Errors (%)</td>
<td>14.80 (11.63)</td>
<td>11.21 (9.43)</td>
<td>10.74 (12.90)</td>
<td>8.69 (9.91)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

The Segmentation contrast was significant, $F(1, 42) = 56.55, p < .001, \eta^2_p = .57$. The Cluster contrast was not significant.

In sum, children of both groups were faster in making lexical decisions about intact than about segmented CCVC (pseudo)words. However, for both groups the mean decision latencies for (pseudo)words with a segmented consonant onset cluster (C#CVC) did not differ from the mean decision latencies for (pseudo)words segmented on the onset-rime boundary (CC#VC).

CVCC Words and Pseudowords

For each condition, the mean error percentages and mean latency scores for both normal and dyslexic readers are presented in the lower part of Table 2.4.

Errors. The mean error percentage for both the normal and dyslexic readers was about 14 to 22% for words and 5 to 14% for pseudowords. There was a main effect for lexicality, $F(1, 42) = 19.82, p < .001, \eta^2_p = .32$, and a marginally significant main effect for position of segmentation, $F(2, 41) = 3.05, p = .058, \eta^2_p = .13$. The first main effect was qualified by a significant interaction with reading group, $F(1, 42) = 5.05, p < .05, \eta^2_p = .11$. No other effects were significant. Overall, children of both groups made more lexical decision errors for words than for pseudowords; however, the dyslexic children made more errors than the normal reading children in the pseudoword condition. The marginally significant position of segmentation effect was examined with follow-up contrasts. The Seg-
mentation contrast was significant, $F(1, 42) = 4.64, p < .05, \eta^2_p = .10$. The Cluster contrast was not significant. Thus, for both normal and dyslexic children, the mean error percentage for segmented (pseudo)words was significantly larger than for intact (pseudo)words, but the mean error percentage between a segmentation within the rime cluster, and a segmentation between onset and rime was not significantly different.

**Latencies.** There were main effects for reading group, $F(1, 42) = 124.62, p < .001, \eta^2_p = .75$; lexicality, $F(1, 42) = 73.03, p < .001, \eta^2_p = .64$; and position of segmentation, $F(2, 41) = 9.08, p < .01, \eta^2_p = .31$. These main effects were qualified by a significant Lexicality $\times$ Reading Group interaction, $F(1, 42) = 25.91, p < .001, \eta^2_p = .38$. This interaction was not proportional, $F(1, 42) = 11.79, p < .01, \eta^2_p = .22$. No other effects were significant. Latency scores were larger for dyslexic than for normal reading children, and larger for pseudowords than for words, but the difference between the mean word and pseudoword latency score was larger for the dyslexic than for the normal readers.

The position of segmentation effect was examined with follow-up contrasts. The Segmentation contrast was significant, $F(1, 42) = 18.53, p < .001, \eta^2_p = .31$. However, the Cluster contrast was not significant.

In sum, children of both groups were faster in making lexical decisions about intact than about segmented CVCC (pseudo)words. However, for both groups, the mean decision latencies for (pseudo)words with a segmented rime cluster (CV#CC) did not differ from the mean decision latencies for (pseudo)words segmented on the onset-rime boundary (C#VCC).

**Additional analyses for effects of grapheme complexity**

The analyses of the CCVVC words have shown that normal and dyslexic children were equally affected by the segmentation of a vowel digraph. However, as can be seen in Tables 2.2 and 2.3, where dyslexic children were slower than the normal readers in their performance on the CCVC structure words, this difference in performance was much larger for the CCVVC structure words.

To examine this trend, we subjected the mean latencies of the intact CCVC and CCVVC words to a MANOVA for repeated measures, with reading group (normal or dyslexic) as a between-subjects factor, and grapheme complexity (CCVC or CCVVC) as a within-subjects factor. Main effects were found for reading group, $F(1, 46) = 32.88, p < .001, \eta^2_p = .42$, and grapheme complexity, $F(1, 46) = 21.65, p < .001, \eta^2_p = .32$. The main effects were qualified by a significant Reading Group $\times$ Grapheme interaction complexity, $F(1, 46) = 13.59, p < .01, \eta^2_p = .23$. This interaction effect remained significant when the MANOVA for repeated measures was applied to a logarithmic transformation of the mean latency scores, $F(1, 46) = 11.44, p < .01, \eta^2_p = .20$. Simple effects revealed that for dyslexic children the mean latency score of words with vowel digraphs was significantly larger
2.3. STUDY 2: ADULT READERS

than the mean latency score for words without vowel digraphs, $F(1, 23) = 22.86$, $p < .01$, $\eta_p^2 = .50$, whereas for normal reading children the mean latency scores of the different word types did not differ.

2.2.3 Discussion

The main finding of this study was that the segmentation of a consonantal onset or rime cluster was equally disruptive as a segmentation between the onset and the rime cluster. Importantly, the reading latencies (both in naming and in lexical decision) of normal reading and dyslexic children were similarly affected. This suggests that, in both normal reading and dyslexic children, consonantal onset and rime clusters are not used as functional units in reading. However, the children of both reading groups were more hampered by the distortion of a vowel digraph cluster than by any other segmentation in a word. This effect was proportionally similar for the dyslexic and normal reading children. Accordingly, both normal reading and dyslexic children seem to use vowel digraph clusters during reading.

As expected, the dyslexic readers were slower than the normal readers in naming and lexical decision. In accordance with many other studies, words were read faster than pseudowords, and this difference was larger in dyslexic readers (Rack, Snowling, & Olson, 1992). Furthermore, the results showed that both reading groups performed worse in naming and lexical decision in the segmentation conditions than in the intact condition.

Finally, we found that, although the normal and dyslexic children were equally affected by the segmentation of a vowel digraph, the dyslexic children were slower in naming intact words with a vowel digraph (e.g., #bloem) than words without a vowel digraph (e.g., #stok). The normal reading children did not differ in the naming of these word types. We elaborate on this issue in Section 2.4.

2.3 Study 2: Adult readers

In the first study, we did not find any evidence that children use consonantal onset and rime clusters as functional units in reading. To exclude the possibility that these clusters had not yet developed in our children, we replicated this study with skilled adult readers.

2.3.1 Method

Participants

Twenty-four students of the University of Amsterdam participated in the CCVC/CVCC naming experiments. One of them did not return for the CCVVC naming and lexical decision task. The ages of the students ranged from 18 years 11 months
to 26 years 8 months. The mean age was 22 years 1 month. All participants were
native speakers of Dutch, had normal or corrected to normal vision, and were not
dyslexic. The participants were paid for their participation in the experiment.

**Tasks and Apparatus**

The design, materials and apparatus were the same as in Study 1. These were
described in Section 2.2.1.

**Procedure**

The students were individually tested in a quiet room. The two sessions were
separated by 2 to 3 weeks.

We applied the same data cleaning procedures and statistical analyses to the
adult data as we used for the children. Because of floor effects, the mean error per-
centage scores were not analyzed. The results on the naming and lexical decision
tasks are presented in separate sections.

### 2.3.2 Results

**Naming**

The percentage of invalid latencies that were attributable to premature responses
and outliers was 2.6% for CCVC (pseudo)words, 6% for CVCC (pseudo)words,
and 3% for CCVVC words. The mean error percentage was 1.3% for CCVC
(pseudo)words, 3.2% for CVCC (pseudo)words, and 0.8% for CCVVC words.
The latency analyses were restricted to the valid and correct trials.

**CCVC Words and Pseudowords** For each condition, the mean error percentages
and mean latency scores are presented in the upper part of Table 2.5. There were
significant effects for lexicality, $F(1, 23) = 38.13, p < .001, \eta_p^2 = .62$; words were
read faster than pseudowords; and position of segmentation, $F(2, 22) = 16.91,
p < .001, \eta_p^2 = .61$. No other effects were significant.

The position of segmentation effect was examined with follow-up contrasts. The Segmentation contrast was significant, $F(1, 23) = 19.31, p < .001, \eta_p^2 = .46$; adults readers were faster in naming intact than segmented (pseudo)words. The Cluster contrast was marginally significant, $F(1, 23) = 4.23, p = .051, \eta_p^2 = .16$. This effect was qualified by a marginally significant Lexicality × Cluster interaction effect, $F(1, 23) = 4.15, p = .053, \eta_p^2 = .15$. Contrary to our expecta-
tions, adult readers tended to name (pseudo)words that were segmented inside
the consonant onset cluster (C#CVC) faster than (pseudo)words that were seg-
mented on the onset-rime boundary (CC#VC), and this effect tended to be more
pronounced for the pseudowords. Simple effects showed that the difference between the C#CVC and CC#VC words conditions was not significant, whereas the C#CVC pseudowords were read significantly faster than the CC#VC pseudowords, $F (1, 23) = 6.40, p < .05, \eta^2_p = .22$.

Table 2.5
Study 2: Mean latency scores and mean error percentages on the two word structures in the different segmentation positions of the CCVC/CVCC naming task for adults.

<table>
<thead>
<tr>
<th>Item type</th>
<th>Latencies</th>
<th>Errors (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Words</td>
<td>Pseudowords</td>
</tr>
<tr>
<td>CCVC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#CCVC</td>
<td>503 (48)</td>
<td>544 (57)</td>
</tr>
<tr>
<td>C#CVC</td>
<td>518 (71)</td>
<td>552 (73)</td>
</tr>
<tr>
<td>CC#VC</td>
<td>522 (64)</td>
<td>570 (60)</td>
</tr>
<tr>
<td>CVCC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#CVCC</td>
<td>500 (56)</td>
<td>529 (48)</td>
</tr>
<tr>
<td>C#VCC</td>
<td>512 (60)</td>
<td>551 (58)</td>
</tr>
<tr>
<td>CV#CC</td>
<td>516 (59)</td>
<td>551 (73)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

**CVCC Words and Pseudowords** For each condition, the mean error percentages and mean latency scores are presented in the lower part of Table 2.5. There were significant effects for lexicality, $F (1, 23) = 21.96, p < .001, \eta^2_p = .49$; words were read faster than pseudowords; and position of segmentation, $F (2, 22) = 18.08, p < .001, \eta^2_p = .62$. No other effects were significant.

The position of segmentation effect was examined with follow-up contrasts. The Segmentation contrast was significant, $F (1, 23) = 37.78, p < .001, \eta^2_p = .62$. The adult readers were found to be faster in naming intact than segmented CVCC (pseudo)words. The Cluster contrast was not significant. The mean naming latencies for (pseudo)words with a segmented rime cluster (CV#CC) did not significantly differ from the mean latencies for (pseudo)words segmented on the onset-rime boundary (C#VCC).

**CCVVC Words** Mean error percentages and mean latency scores in the different segmentation conditions are presented in Table 2.6.

We found a significant effect for position of segmentation, $F (3, 20) = 14.06, p < .001, \eta^2_p = .68$. The position of segmentation effect was examined with follow-up contrasts. The Segmentation contrast was significant, $F (1, 22) = 4.38, p < .05, \eta^2_p = .17$. The mean naming latency score of the adult readers was significantly higher for segmented than for intact words. The Digraph contrast was also significant, $F (1, 22) = 41.42, p < .001, \eta^2_p = .65$. The latency scores were larger for words that were segmented inside than for words that were segmented outside the vowel digraph.


Table 2.6  
Study 2: Mean latency scores and mean error percentages on the CCVVC words in the different segmentation positions of the digraph naming task for adults.

<table>
<thead>
<tr>
<th>Item type</th>
<th>Latencies</th>
<th>Errors (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#CCVVC</td>
<td>519 (59)</td>
<td>0.43 (2.09)</td>
</tr>
<tr>
<td>C#CVVC</td>
<td>526 (54)</td>
<td>0.43 (2.09)</td>
</tr>
<tr>
<td>CCV#VC</td>
<td>585 (83)</td>
<td>1.35 (3.58)</td>
</tr>
<tr>
<td>CCVV#C</td>
<td>537 (65)</td>
<td>0.87 (2.88)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

Lexical Decision

The percentage of invalid latencies due to premature responses and outliers was 3.3% for CCVC (pseudo)words and 3.8% for CVCC (pseudo)words. The mean error percentage was 4.2% for CCVC and 5.5% for CVCC (pseudo)words. The results are presented separately for each word type. The latency analyses were restricted to the valid and correct trials.

CCVC Words and Pseudowords  For each condition, the mean error percentages and mean latency scores are presented in the upper part of Table 2.7. There were significant main effects for lexicality, $F(1, 22) = 18.33, p < .001, \eta^2_p = .46$; words were read faster than pseudowords. There also was a significant main effect for the position of segmentation, $F(2, 21) = 16.86, p < .001, \eta^2_p = .62$. In addition we found a marginally significant Lexicality $\times$ Position of Segmentation interaction effect, $F(2, 21) = 3.42, p = .052, \eta^2_p = .25$. For adult readers, the decision speed for CCVC words tended to be more influenced by segmentation than the decision speed for CCVC pseudowords.

The position of segmentation effects were examined with follow-up contrasts. The Segmentation contrast was significant, $F(1, 22) = 23.69, p < .001, \eta^2_p = .52$. This effect was qualified by a marginally significant Lexicality $\times$ Segmentation interaction, $F(2, 21) = 3.42, p = .052, \eta^2_p = .25$. The mean decision latency was larger for segmented (pseudo)words than for intact (pseudo)words. However, this effect tended to be more pronounced for words than for pseudowords. The Cluster contrast was also significant, $F(2, 21) = 8.79, p < .01, \eta^2_p = .29$. The adult readers responded faster when the segmentation was inside the consonant onset cluster (C#CVC) than when the segmentation was between onset and rime (CC#VC). The Cluster $\times$ Lexicality interaction was not significant; the effect was similar for words and pseudowords. Like the results of the CCVC naming task, this finding is contrary to our expectation that segmentation within the consonantal onset cluster would lead to a larger decrease in lexical decision performance than segmentation between the onset and rime.
CVCC Words and Pseudowords  For each condition, the mean error percentages and mean latency scores are presented in the lower part of Table 2.7. We found a marginal main effect for lexicality, $F(1, 22) = 3.34, p = .081, \eta_p^2 = .13$, responses to pseudowords tended to be slower than responses to words; and a significant main effect for position of segmentation, $F(2, 21) = 18.07, p < .001, \eta_p^2 = .63$. No other effects were significant.

Table 2.7
Study 2: Mean latency scores and mean error percentages on the two word structures in the different segmentation positions of the lexical decision task for adults.

<table>
<thead>
<tr>
<th>Item type</th>
<th>Latencies</th>
<th>Errors (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Words</td>
<td>Pseudowords</td>
</tr>
<tr>
<td>CCVC</td>
<td>623 (63)</td>
<td>709 (92)</td>
</tr>
<tr>
<td>C#CVC</td>
<td>672 (90)</td>
<td>727 (110)</td>
</tr>
<tr>
<td>CC#VC</td>
<td>707 (83)</td>
<td>741 (90)</td>
</tr>
<tr>
<td>CVCC</td>
<td>649 (63)</td>
<td>692 (88)</td>
</tr>
<tr>
<td>C#VCC</td>
<td>704 (74)</td>
<td>719 (102)</td>
</tr>
<tr>
<td>CV#CC</td>
<td>720 (71)</td>
<td>739 (120)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

The position of segmentation effect was examined with follow-up contrasts. The Segmentation contrast was significant, $F(1, 22) = 37.16, p < .001, \eta_p^2 = .63$. The mean decision latencies were found to be larger for segmented than for intact (pseudo)words. The Cluster contrast was marginally significant, $F(1, 22) = 3.83, p = .063, \eta_p^2 = .15$, the adult readers tended to respond faster when the segmentation was on the onset-rime boundary (C#VCC) than when the segmentation was inside the rime (CV#CC).

2.3.3 Discussion

We found that the reading latencies of skilled adult readers did not decrease more when a (pseudo)word was segmentated within a consonantal onset cluster than when the segmentation between onset and rime. Contrary to our prediction, and unlike the findings in children, we found the opposite pattern: the segmentation of a consonantal onset cluster had a smaller negative effect on reading latencies than segmentation outside the cluster, that is, between onset and rime. This effect was found in naming and lexical decision tasks, although in the naming task the effect was mainly because of the pseudowords.

With respect to the rime cluster, only a small and nonsignificant trend was found in lexical decision toward a faster responding to (pseudo)words with intact rimes than to (pseudo)words with a distorted rime. For naming, the effect of a distortion between onset and rime was similar to a distortion within the rime clus-
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ter. As in the first study with children, the results do not provide evidence for the use of consonantal onset and rime clusters as functional units in reading. The pattern of results on the CCVC and CVCC (pseudo)words seems better compatible with the hypothesis that reading is hampered more if a segmentation appears more toward the end of the word. We will elaborate on this issue below.

Finally, as the younger readers in the first study, the skilled adult readers were more hampered when a vowel digraph cluster was segmented than by segmentation in another position of a word.

2.4 General Discussion

The main aim of our study was to examine the use of consonantal onset clusters by normal reading and dyslexic children, and by adults. As in previous studies (Bowey, 1996; Levitt et al., 1991; van den Bosch, 1991), the insertion of a nonletter symbol between the two letters of the consonantal onset cluster did not hamper reading more than if this segmentation was between the onset and the rime of a word. Given this segmentation paradigm, the results therefore provide little evidence for the use of these clusters as functional units in the reading of children and adults. Unexpectedly, the adult readers were even faster in reading words with segmented onsets compared to (pseudo)words that were segmented on the onset rime boundary.

We also examined the use of the rime cluster. For both normal reading and dyslexic children, the segmentation within the rime cluster had a similar effect as the segmentation outside the rime cluster, that is, between onset and rime. This result suggests that children do not use rime clusters during reading. On the naming tasks, the adult data showed the same pattern as for the children, converging with the earlier findings of van den Bosch (1991), but the lexical decision speed of the adult readers was somewhat slower when the rime cluster was distorted than when the rime cluster was left intact. Treiman and Chafetz (1987) and van den Bosch (1991) found similar results for lexical decision performance in adult readers.

Although the findings in these studies and our study might provide some support for the use of the rime cluster in reading, these findings can also reflect a position of segmentation effect, as the distortion of the rime cluster is more toward the end of the word than a segmentation between onset and rime. Such a position of segmentation effect can also explain our unexpected finding that the segmentation of the onset consonant cluster in (the beginning of) CCVC words and pseudowords had a smaller effect on reading latencies than a segmentation between onset and rime that was relatively more toward the end of the word. Given these equivocal results in lexical decision and the absence of an effect in naming, the current evidence does not seem to provide support for the use of the rime as a functional unit in adult reading. Although word reading was not specifically
affected by the segmentation of the consonantal onset or rime cluster, we did find that both children and skilled adult readers were affected by the distortion of a digraph. A similar finding was reported by van den Bosch (1991) with grade-1 readers and by Martensen et al. (2003) in skilled adult readers. This specific status of digraphs is also in accordance with the results of Rey, Ziegler, & Jacobs (2000). Using a letter detection paradigm, Rey et al. found that vowel detection was slower when the target vowel was embedded within a digraph unit (e.g., e in peach) than when the vowel corresponded to a single letter grapheme (e.g., e in bench). In addition to previous studies, we found that dyslexic readers were equally able as normal readers in processing digraphs as units, as the distortion of a digraph within a word had a similar effect on both reading groups.

Martensen et al. (2003) hypothesized that the segmentation of a digraph disrupts a visual parsing process of the letters in a word takes place before orthographic units are mapped onto phonological units. Following the PDP model of Plaut et al. (1996), Martensen et al. also hypothesized that onsets and codas are formed by visual parsing, and thus should be susceptible to segmentation as well. However, the results of our study provide little support for this latter hypothesis, because we found no segmentation effect for consonantal onset and rime clusters.

Of interest, the parsing of letters into graphemes has been implemented in a recent computational model of reading, the Connectionist Dual Processing Model (CDP+) of Perry, Ziegler, and Zorzi (2007). The model involves a graphemic buffer (see Figure 4 on p. 280). According to the model, the letters of a word are parsed or translated into graphemes, which in turn are connected to phonological units. However, the specific mechanism by which letters are parsed into graphemes is not yet fully understood. In addition, the assumption that only letters are parsed that map onto a grapheme needs further study, as it should be noted that, at least in Dutch education, children are explicitly instructed to decode digraphs as a unit. The possibility remains, therefore, that consonantal onset clusters and rimes might also become to function as perceptual units in reading if these clusters are explicitly taught as a unit.

The dyslexic readers of our study were equally affected by the segmentation of a digraph as their normal reading peers. From the assumption that such a segmentation disrupts visual parsing, it follows that dyslexic readers do not seem to have particular problems with this early visual process. However, we did find a difference between the two reading groups in the reading of intact words. Normal reading children were equally fast in reading intact words containing a digraph (e.g., #stoel [chair]) and reading intact words without a digraph (e.g., #stop). Also, the skilled adult readers in our second study were not affected by a digraph, as was previously found by Martensen et al. (2003). In contrast, the naming speed of dyslexic children was slower for words with than for words without a digraph. Similarly, Elbro (2005) found that, across orthographies, beginning readers need more time to learn pseudowords with a digraph. Thus, digraphs might pose spe-
specific problems for beginning and dyslexic readers. However, the latter assertion should be regarded with considerable caution. In our study, the words with digraphs were also longer, and dyslexic children have been regularly found to be extra affected by additional letters in a word (e.g., Ziegler et al., 2003; Zoccolotti et al., 2005).

The results of our study are also relevant for current computational and developmental theories of reading. The results are partially in line with the predictions of the DRC model (Coltheart et al., 2001). In this model, letters are the functional units of reading and consonantal onset and rime clusters are not involved. The latter was also found in our study. However, our finding that vowel digraphs are vulnerable to segmentation, and therefore seem to function as a perceptual unit, is clearly not in accordance with the DRC model. In contrast, connectionist models (Plaut et al., 1996; Taft, 1991) do predict that vowel digraphs are used as units during reading. However, connectionist models also predict that sublexical clusters emerge as a result of the learning of a distributed network, and this was not found in our study.

With respect to developmental theories of reading, the current results provide little evidence for Ehri’s (1992; 1998) consolidated alphabetic phase in which associations are acquired between multiletter units and their corresponding phonological segments in spoken words. Our findings seem to converge with PGS theory (Ziegler & Goswami, 2005). According to PGS, the use of sublexical units is primarily dependent on the consistency of the grapheme to phoneme mappings of the orthography. As Dutch is a relatively regular orthography, PGS would predict that consonantal onset clusters and rimes will not be used, and this is exactly what was found in our study. However, it should be acknowledged that a true verification of the PGS theory could only be accomplished by comparing the findings of our study with the same experiments conducted in an inconsistent orthography, like English. In this case, the PGS theory would postulate that there would be a segmentation effect for inconsistent consonantal onset clusters and rimes.

As was argued in the introduction of the article, enhancing the use of sublexical clusters has been the focus of a number of interventions that were meant to improve the reading fluency of dyslexic readers. In these interventions, the use of clusters has been stimulated with visual manipulations that aimed to increase the visual saliency of the target cluster. Evidence suggests that the effects of these visual manipulations tend to be small. This seems understandable, as in our study it was not possible to demonstrate with a visual manipulation (i.e., the segmentation paradigm) that the reading of normal readers (children and adults) was specifically hampered when a presumed cluster (onset or rime) was disrupted. Of course, this finding does not necessarily imply that interventions aimed to stimulate the use of sublexical clusters should be abandoned. But it does suggest that it might be better to shift focus from an emphasis on the visual saliency of letter clusters to methods that enhance the link between orthographic and phonological clusters.