Word-recognition processes in normal and dyslexic readers
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Chapter 1

General introduction

Fluent reading has become an increasingly crucial prerequisite to functioning adequately in modern society. Reading, defined as the ability to convert written into spoken word forms, can be considered a relatively young cognitive skill. Although the Egyptian elite acquired the competence about five thousand years ago, it has barely been a hundred years since compulsory education introduced reading to the general population in Western societies (Dalby, 1986).

Not surprisingly, the interest in reading disabilities, and dyslexia in particular, arose more or less simultaneously with the introduction of compulsory education. The first publication on developmental dyslexia, or “congenital word blindness”, appeared just before the beginning of the twentieth century (Pringle-Morgan, 1896). Nowadays, developmental dyslexia is defined as a specific learning disability characterized by difficulties in acquiring basic reading subskills such as word identification and phonological (letter-sound) decoding. It is a widespread phenomenon, since up to 10% of all school age children are estimated to experience difficulties in learning to read (Vellutino, Fletcher, Snowling, & Scanlon, 2004). For children learning to read in more transparent languages, like Dutch, the prevalence of dyslexia is estimated to be somewhat lower, between 4% to 8% (Blomert, 2005; van der Leij et al., 2004). Dyslexia can have far-reaching consequences, including failure to complete basic education and socio-emotional problems like anxiety and depression (Bosman & Braams, 2005; Carroll, Maughan, Goodman, & Meltzer, 2005).

The growing awareness of the importance of reading during the last century is also reflected by an explosion of research into reading over the last four to five decades, as evidenced by dozens of specialist journals, international conferences and the founding of societies focusing on reading and dyslexia. The major aim of reading research has been to disentangle the complex cognitive processes involved in reading and reading acquisition with the ultimate goals of determining the causes of dyslexia and the development of adequate reading interventions.
CHAPTER 1. GENERAL INTRODUCTION

Although a century of scientific studies on reading has resulted in a remarkable accumulation of knowledge (Snowling & Hulme, 2007), the reading process is still not fully understood and there is certainly no standard cure for dyslexia. Therefore, the aim of the current thesis is to expand the current understanding of visual word-recognition processes in normal and dyslexic readers. In particular, I will focus on causes that might underlie the slow and laborious reading that is commonly observed in dyslexic children.

1.1 Reading-fluency impairments in dyslexic children

Proficient reading is characterized by a high level of accuracy and automaticity (Kuhn & Stahl, 2003). The latter forms the basis of skilled reading as it allows readers to focus all their attention on the meaning of the text. Dyslexic readers typically fail to develop the ability to automatically and effortlessly recognize words, resulting in slow reading.

Because dyslexic readers have difficulties recognizing words instantaneously, they are thrown back on using more sublexical, letter-by-letter reading strategies to decode a word (Barca, Burani, di Filippo, & Zoccolotti, 2006; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Zoccolotti et al., 1999). In the meantime, normally developing children naturally progress from a serial reading strategy to more efficient parallel word-recognition strategies (Share & Stanovich, 1995).

In transparent orthographies, like Dutch, Italian and German, even dyslexic readers usually become quite accurate readers (de Jong & van der Leij, 2003; Spinelli et al., 2005; Wimmer, 1993). Languages with transparent orthographies are characterized by consistent letter (graphemes) to sound (phoneme) mappings. As a result of these consistent mappings, it is relatively easy to convert the written letters of a word into their corresponding sounds. A letter-by-letter reading strategy is still laborious, but at least it is likely to result in the correct identification of a word. However, in languages with inconsistent orthographies like English, the letter-to-sound mappings are quite irregular. Therefore, it is much more difficult to decode an English word with a letter-by-letter reading strategy than a word in a transparent language. As a consequence, dyslexic readers learning to read English not only show profound difficulties in developing reading speed, but also in developing reading accuracy. However, in English, difficulties in developing reading speed also seem to be the more persistent problem, as intervention studies with English dyslexic readers have shown that it is much easier to enhance reading accuracy than reading speed (Torgesen et al., 2001).

In sum, the development of automatic word recognition seems to be the most persistent problem in dyslexic children. To be able to design proper interventions to remediate their slow reading, first the specific processes that underlie the development of direct word recognition need to be identified.
1.2 Theories on the development of word recognition

Below I will present a short overview of two influential theories on the development of word recognition: Ehri’s phase theory (1998) and the self-teaching hypothesis of Jorm, Share, Maclean and Matthews (1984). According to phase or stage theories, the development of skilled word reading can be characterized by a succession of different phases, or stages, in which the type of associations between the written and spoken form of words tends to change systematically. In contrast, the self-teaching hypothesis (Jorm et al., 1984; Share, 1995), describes the development of word recognition as a continuous process, albeit an item-based one. After the presentation of the two theories, it will be evaluated to what extent they provide a theoretical framework to examine and compare word-recognition processes in normal reading and dyslexic children.

1.2.1 Ehri’s phase theory

There are at least eight different phase or stage theories (Ehri, 2007). For this Introduction I chose to give a brief review of Ehri’s phase theory (1992; 1998) as it can be regarded as one of the most influential phase theories and is representative for phase theories of reading in general. The four phases of Ehri’s theory are described below.

The starting point of Ehri’s phase theory is the pre-alphabetic phase. In this phase children recognize a word based on a salient visual cue. These visual characteristics, for instance the yellow M of McDonalds, do not involve letter-sound relations, as children reading in the pre-alphabetic phase are not yet able to use the alphabetic principle to decode a word. However, as soon as children master a few letter-sound correspondence rules, they move on to the next phase, the partial-alphabetic phase. In the beginning, when children are only able to use a few letter-sound correspondences, their reading is quite inaccurate, because often more or even all letter-sound correspondences are required to correctly identify a word (Jackson & Coltheart, 2001b). When children master all the letter-sound correspondence rules, they enter the third phase, the full-alphabetic phase. From this stage on children are able to form connections between all letters in a word and phonemes in the corresponding pronunciation to remember how to read the word. In normal reading children, only one or a few of such encounters with an unfamiliar word are sufficient to convert it into a sight word, meaning that the word can be automatically recognized. In the final phase of Ehri’s phase theory, the consolidated-alphabetic phase, children learn to activate letter sequences that symbolize blends of grapho-phonemic units, including morphemes, onsets and rimes. But also monosyllabic words that have become sight words and more frequently occurring spellings of syllables in polysyllabic words (Ehri, 2007).

Ehri’s phase theory was originally developed to describe the process of nor-
mal reading development and has been used as a starting point for many studies examining reading acquisition (e.g., Bowman & Treiman, 2002; Share & Gur, 1999). However, researchers have come to acknowledge that the question of how the reading of dyslexic children fits in the developmental phases deserves more attention (Ehri & Snowling, 2004).

1.2.2 The self-teaching hypothesis

Instead of focusing on different phases of reading development, the self-teaching hypothesis describes the development of skilled word recognition in terms of the acquisition of orthographic knowledge (Share, 1999; Share, 1995). Put simply, before children are able to directly recognize a word, they need to build up specific knowledge about its written form. According to the self-teaching hypothesis the only way to build up such orthographic knowledge is by means of phonological recoding: the conversion of unfamiliar words into their spoken counterparts. As soon as children are familiar with the alphabetic principle, they are able to build their own store of orthographic knowledge, which in turn enables them to automatically recognize words.

As dyslexic children are known to suffer from impairments in the representation, storage and retrieval of speech sounds (Snowling, 2000), it is conceivable that this leads to difficulties with phonological recoding, which in turn might hamper their development of orthographic knowledge. Previous studies with English and Dutch children (Ehri & Saltmarsh, 1995; Manis, 1985; Reitsma, 1983) indeed found that reading-disabled children needed much more exposure and training than normal reading children to acquire the same level of orthographic knowledge. In addition, Share and Shalev (2004) found that reading-disabled children learning to read Hebrew showed impaired orthographic learning relative to normal reading children.

1.2.3 Limitations of current developmental theories

On the basis of Ehri’s phase theory and the self-teaching hypothesis, it can be concluded that the acquisition of fast and automated word recognition is a direct consequence of the development of orthographic knowledge, that is, a system of associations between phonology and orthography. Indirectly, it can also be deduced that failure to build up orthographic knowledge will lead to problems in developing reading speed. Indeed, it has been found that reading-disabled children are slower in building up such orthographic knowledge (Ehri & Saltmarsh, 1995; Manis, 1985; Reitsma, 1983).

However, to be able to pinpoint the causal processes underlying the slow and laborious reading of dyslexic children—which is the aim of the current thesis—more specific predictions than those that are currently provided by developmental
word-recognition theories are needed (see also Beech, 2005, for a short critique on Ehri’s phase theory). For instance, the self-teaching hypothesis postulates that phonological recoding is the key mechanism behind orthographic learning. The definition of phonological recoding, however, is very broad. In fact, it is used as an “umbrella term for the process of print to sound conversion by whatever means this is accomplished” (Share, 2008, page 35). As a consequence, the self-teaching hypothesis in its current state does not provide a starting point for specific predictions about the nature of phonological recoding (de Jong, Bitter, van Setten, & Marinus, 2009). To start with, it remains unclear whether children only use letter-sound correspondences to decode words or whether they also learn to complement these mappings with the use of larger units like onset clusters, rimes or syllables. It is also unclear how inconsistencies like multigrapheme units (e.g., the *ou* in *soup*) are resolved. This is in contrast to Ehri’s phase theory, which does assume a shift from more finely grained associations between all individual letters and corresponding sounds towards connections between larger letter clusters and sound mappings.

However, like the self-teaching hypothesis, the phase theory does not make explicit predictions about differences in phonological recoding between normal and dyslexic readers. In addition, neither the self-teaching hypothesis, nor the phase theory describes whether phonological recoding is applied in a serial, left to right, or parallel fashion. Both issues, learning to use larger clusters in word recognition and the nature of phonological recoding, are highly relevant factors in comparing the development of word recognition in normal reading and dyslexic children. Especially the first issue, the acquisition and use of larger clusters in word recognition, will be examined in this thesis.

### 1.3 Framework to examine word-recognition processes

In contrast to developmental theories, models of skilled word-reading are more explicit in describing the processes that precede the recognition of a word. Especially in the Dual-Route Cascaded model (DRC model, Coltheart et al., 2001) and the Connectionist Dual Process model (CDP+ model, Perry, Ziegler, & Zorzi, 2007) such processes are meticulously defined. Due to their explicitness, these models provide a useful framework for formulating hypotheses about and for examining proximal causes of word-recognition problems of dyslexic readers (see also Ziegler et al., 2008).

Proximal causes are defined as processes within a stated or implied model of the reading system as it is functioning at a particular time, and they always refer to processes on the cognitive level (Jackson & Coltheart, 2001a). By testing causal links between properties of a hypothesized (dyslexic) reading system and specific reading behaviour, the experimental approach of the current thesis differs from
reading-development studies focusing on more distal causes of reading problems. The latter approach typically investigates the contribution of factors like general cognitive ability, verbal ability, phonological memory, phonological awareness and letter-name knowledge in predicting individual differences in reading ability or development (Bowey, 2007). The current thesis, however, specifically focuses on differences between the dyslexic and normal reading system as it is functioning during the recognition of a word.

In the DRC and CDP+ models of the reading system, a distinction is made between a sublexical and a lexical route in the recognition of words and pseudowords. In the sublexical route, letters or graphemes are processed in a sequential left-to-right, one-by-one fashion. Therefore, extra reading time will be required for each additional letter, or grapheme, in a word or pseudoword. In contrast, in the lexical route all letters of a word are processed in parallel and immediately trigger the orthographic representation of the word in an orthographic lexicon. As a result, the number of letters in a word does not affect the reading time. The two routes operate simultaneously, with the relative contribution of the lexical route depending on whether the target word is familiar (i.e., represented in the orthographic lexicon), but also on how many similar words are available in the orthographic lexicon. As pseudowords are not in the orthographic lexicon, the contribution of the sublexical route will be larger. In contrast, the lexical route will be more important in recognizing exception words, as the application of grapheme-phoneme correspondence rules will not lead to the correct pronunciation of such a word (Coltheart et al., 2001). The distinction between exception words and pseudowords is very relevant in studying word-recognition processes in languages with inconsistent orthographies like English (see also Section 1.1). However, in languages with more transparent orthographies, like Dutch, it is more relevant to distinguish between unfamiliar and familiar words (Share, 2008).

### 1.3.1 Sublexical processes in word recognition: Which are the functional units of print?

The lion’s share of the current thesis (Chapters 2 to 5) focuses on sublexical processes in word recognition in normal and dyslexic readers. Important issues concern the size of the functional units in word recognition, whether the use and size of these units change during reading development, and potential differences between normal and dyslexic readers in the use of these units.

Within monosyllabic words, three different units can be distinguished. Firstly, sublexical clusters, units larger than one letter, but smaller than a word like consonant clusters (e.g., st in stop or spl in split), bodies (e.g., sto in stop), and rimes (e.g., op in stop). Secondly, graphemes, referring to all letters and letter combinations that represent a phoneme, including digraphs, such as f, ph, and gh for the phoneme /f/. Finally, the letters, representing the smallest units. Below, I will
elaborate on how differences in the use of these different units might account for the word-recognition problems in dyslexic children and outline how the use of these different clusters will be examined in the current thesis.

**The use of sublexical clusters in reading: Consonantal onset clusters and rimes**

Examining the use of sublexical clusters in the reading development in normal reading and dyslexic children is important from both theoretical and practical perspectives. Firstly, the profound difficulties dyslexic children experience in developing reading speed might be partly explained by a failure to use larger letter clusters as functional units in reading. In terms of Ehri’s phase theory (Ehri, 1992, 1998), this would mean that children with dyslexia do not reach the consolidated-alphabetic phase. In response to this assumption a large number of studies have been conducted, using several techniques to improve the use of larger letter clusters in poor and dyslexic readers (Das-Smaal, Klapwijk, & van der Leij, 1996; Hintikka, Landerl, Aro, & Lyytinen, 2008; Huemer, Landerl, Aro, & Lyytinen, 2008; Levy, 2001; Thaler, Ebner, Wimmer, & Landerl, 2004; van Daal, Reitsma, & van der Leij, 1994). Unfortunately, however, the effects of such interventions have been rather small. This finding might implicate that an increasing ability to use sublexical clusters is not the underlying mechanism behind the development of reading speed. However, it might also be the case that the proper way of stimulating the use of sublexical clusters in reading has not been found yet.

Secondly, studying the use of sublexical clusters is of theoretical interest as the assumptions of current computational models of word recognition differ in their treatment of these units. In most connectionist single-route models sublexical clusters have been explicitly built into the model or are an emergent property of the learning of a distributed network (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996). In contrast, sublexical clusters are not represented in the Dual-Route Cascaded model (Coltheart et al., 2001).

However, with the exception of the computational-modelling work of Harm and Seidenberg (1999), possible differences in learning to use sublexical clusters in reading between normal and dyslexic readers have not yet been implemented in computational models of reading. This is surprising, because less use of sublexical clusters might not only form a plausible explanation for the slower reading of dyslexic children, but also for the finding that they respond more strongly to two important marker effects. These marker effects are the Lexicality effect, the finding that it takes longer to read unfamiliar than familiar words, and the Length effect, the observation that longer words and pseudowords are read more slowly and less accurately than shorter words and pseudowords (Martens & de Jong, 2006; Rack, Snowling, & Olson, 1992; Ziegler et al., 2003; Zoccolotti et al., 2005). The latter effect tends to be especially strong for pseudowords (Balota, Cortese, Sergent-Marshall, & Spieler, 2004). If dyslexic children make less use of sublexi-
cal clusters, then indeed the slowing down in their reading speed is predicted to be stronger for pseudowords, especially longer pseudowords, than for words, which in turn explains their more pronounced Lexicality and Length effects.

Despite the practical and theoretical relevance, studies investigating the use of sublexical clusters in children, and especially dyslexic children, are scarce. In this thesis the use of sublexical clusters will be examined in both normal and dyslexic readers by using different experimental paradigms. The question whether dyslexic children are less proficient in using consonantal onset clusters (e.g., \textit{st} in \textit{stop}) and rimes (e.g., \textit{op} in \textit{stop}) during word recognition than normal reading children will be addressed in Chapter 2. The use of these clusters in normal reading and dyslexic children was examined with naming and lexical decision tasks in which the consonantal onset and rime clusters of the target words and pseudowords were visually distorted with a hash (e.g., \textit{s#top}). To further examine the role of the use of consonantal onset clusters in the development of word-recognition speed, an intervention study was conducted. A novel training was developed in which the use of consonantal onset clusters as blended units was explicitly trained. This training study is presented in Chapter 5.

The use of graphemes: Are digraphs perceptual units in reading?

As described earlier, graphemes are defined as all letters and letter combinations representing a phoneme. Since there are more phonemes than letters in the alphabet, there are also a large number of graphemes that consist of two or even more letters (Borgwaldt, Hellwig, & de Groot, 2004). A grapheme that consists of two letters is called a digraph. Digraphs are a high-frequent phenomenon in Germanic languages like English and Dutch. For example, in Dutch 50\% of all monosyllabic words contain one or more digraphs (Baayen, Piepenbrock, & van Rijn, 1993). Digraphs (and trigraphs) can be considered a special category within the larger family of sublexical clusters because, in contrast to for instance onset clusters and rimes, there are more letters mapping onto one sound.

Previous studies showed that words containing digraphs are more difficult for beginning readers than words consisting of single-letter graphemes only (Elbro, 1996). This is probably due to the fact that a child has to become used to mapping one sound onto two letters that were previously taught as having different letter-sound mappings when encountered in isolation, that is, outside of the context of a digraph. Compare, for instance, the pronunciation of the /o/ in \textit{stop} and the /u/ in \textit{stuff} to their joint pronunciation in \textit{soup}.

Because beginning and dyslexic readers are known to use more serial letter-by-letter reading strategies (Zoccolotti et al., 1999), it is conceivable that an encounter with a digraph may slow down their reading speed. One way to solve the inconsistency of a digraph is to process the two letters as a perceptual unit. It might be that beginning readers and dyslexic children are less proficient in processing di-
graphs as perceptual units, which in turn may form an explanation for their slower reading speed.

The question whether digraphs are processed as perceptual units and whether dyslexic readers are less proficient in doing so, is not only interesting in explaining reading speed differences between normal and dyslexic readers, but also important from a theoretical point of view. Within the Dual-Route Cascaded model, perceptual processing (i.e., before the sounds are mapped onto the letters) strictly pertains to the letter level. The inconsistency of a digraph is not resolved until the sounds are mapped onto the separate letters (Coltheart et al., 2001). In contrast, the CDP+ model postulates a graphemic-buffer layer in which words are parsed into graphemes (and not into letters) before the sounds are mapped onto the graphemes.

In the present thesis, the processing of digraphs in normal and dyslexic readers is examined in three different studies. Two studies will focus on perceptual processing by using a segmentation paradigm (Chapter 2) and a visual letter-detection paradigm (Chapter 3). Finally, in Chapter 4, I will examine whether the presence of a digraph slowed down word and pseudoword naming speed and whether this effect was more pronounced in dyslexic children.

**Zooming in on the length effect: Is it letter based or grapheme based?**

The issue whether digraphs are visually parsed before the sounds are mapped onto the graphemes is inextricably connected to the question whether the Length effect is based on the number of letters or number of graphemes. Similarly, it is also related to one of the previously raised questions about the nature of phonological recoding (Share, 1995). Do children recode familiar words letter by letter or grapheme by grapheme?

The Length effect has been thoroughly investigated in both normal and dyslexic readers (Balota et al., 2004; Martens & de Jong, 2006; Spinelli et al., 2005; Weekes, 1997). As mentioned in Section 1.3.2, dyslexic children have typically been found to respond more slowly and less accurately to longer words and pseudowords than to shorter words and pseudowords compared with normal readers. However, it should be noted that these earlier studies selected their stimuli based on number of letters only, without taking the presence of digraphs into account (e.g., Martens & de Jong, 2006; Ziegler et al., 2003). As a result, it is still unclear whether the word-length effect is based on number of letters or number of graphemes. Compare for instance the words *stop* and *soup*. The first word consists of four letters and four graphemes, whereas the second, because of the presence of the digraph, consists of four letters and three graphemes. In addition, none of the Italian studies, comparing word-length effects in normal and dyslexic readers (e.g., Spinelli et al., 2005, Zoccolotti et al., 1999), controlled for the influence of syllable length.
To resolve the question whether the Length effect and the more pronounced Length effects in dyslexic children are based on number of letters or number of graphemes, a naming study was conducted. In this study, which is presented in detail in Chapter 4, only monosyllabic words were included to avoid possible confounds with syllable length.

1.3.2 Lexical processes in word recognition: Sensitivity to neighbourhood size

Within the self-teaching hypothesis (Share, 1995); (Section 1.2.2), phonological recoding is described as an umbrella term for the process of print-to-sound conversion. In the previous sections, phonological recoding was linked to the sublexical route. However, within the definition of the self-teaching hypothesis, words and pseudowords can also be recoded by analogy with familiar words, that is, via lexical instead of sublexical processing.

Lexical processing involves the retrieval of a whole-word pronunciation from a knowledge base of such pronunciations (Jackson & Coltheart, 2001b). The first four studies in the present thesis all focus on differences in sublexical reading processes between normal and dyslexic readers. However, it might also be the case that the reading-speed deficit of dyslexic readers results from deficits in lexical processing. For instance, Barca et al. (2006) argued that the persistent letter-by-letter reading strategy of dyslexic readers might be a consequence of an inability to use or build up lexical knowledge. In addition, studying word recognition from the perspective of the self-teaching hypothesis, a number of studies have found that dyslexic children experience difficulties in building up orthographic knowledge (Ehri & Saltmarsh, 1995; Manis, 1985; Reitsma, 1983).

Therefore, in the final study in Chapter 6, two different marker effects were used to compare lexical processing between normal reading and dyslexic children, namely sensitivity to orthographic neighbourhood size (N-size) and sensitivity to the presence of a high-frequent neighbour. Previous research with skilled readers has shown that words and pseudowords with many neighbours, like cat (which has several neighbours including cap, bat and cut), are read faster and more accurately than words with fewer neighbours (Andrews, 1997). The only earlier study investigating N-size effects in dyslexic children is a study of Ziegler et al. (2003). However, this study focused on the body neighbourhood. In contrast to general N-size, body N-size is the sum of words that can be formed by changing only the first letter of a target word (e.g., neighbours of hit are bit and lit, but not hip). It was found that dyslexic children showed normal facilitatory body N-size effects. Comparing the influence of the presence of a high-frequent neighbour on word-recognition speed in normal and dyslexic readers has not been done before and can therefore be considered a novel approach to investigate differences in lexical structuring and processing in normal and dyslexic readers.
1.4 Summary of the focus and outline of this thesis

The current thesis aims to examine differences between the normal and dyslexic reading system in order to find explanations for the slow and laborious reading of dyslexic readers. Following computational models of reading (Coltheart et al., 2001; Perry et al., 2007), a distinction is made between sublexical and lexical processes in the reading system. The majority of the studies in the present thesis (Chapters 2 to 5) focuses on sublexical processing. The main aim of these studies is to identify the functional units of print and whether normal and dyslexic readers differ in their ability to use these units. Finally, in Chapter 6, potential differences in lexical processing will be examined.