How do children read words? A focus on reading processes

van den Boer, M.

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So, please, oh please, we bet, we pray,
go throw your TV set away,
and in its place you can install,
a lovely bookshelf on the wall.

- Roald Dahl -

Chapter 1
General Introduction

Being able to read is very important in our literate society. Try to imagine grocery shopping without being able to read the labels on products, travelling without being able to read signs, or simply going through the day without checking your smartphone. I am sure you cannot. Luckily most children learn to read fluently in only a short amount of time. Some children, however, struggle a little, or even a lot more and suffer from reading disabilities. Dyslexia, the specific learning disability characterized by difficulties with accurate and/or fluent word recognition and/or spelling (e.g., Kleijnen et al., 2008; Lyon, Shaywitz, & Shaywitz, 2003), affects about 3 to 10 percent of the population, depending on the precise definition and criteria used for its diagnosis (Snowling, 2013).

Because reading is such an important skill, many studies have examined reading and reading development. Most of these studies can be roughly divided into two categories. On the one hand, a line of research focused on the development of the reading system. On the other hand, there are studies that have identified cognitive skills that foster reading performance. According to prominent theories of reading development, there is a gradual shift in the reading processes underlying word identification. Initially, children rely mainly on serial strategies to read words, such as sounding out letters one-by-one. Throughout development, however, children become able to process letters in parallel, and retrieve whole word forms from memory. Studies that focused on reading related cognitive skills have, for example, identified phonological skills as important predictors of reading performance. Although this implies that phonological skills somehow affect the way in which children read words, the relations with reading processes have rarely been specified. The majority of the studies within this line of research focused on the relation between cognitive skills and the outcome of the reading system in terms of reading speed or accuracy. In other words, there is a gap between studies that focused on reading processes and the reading system, and studies that identified cognitive skills that foster reading performance. There are few studies that considered the relation between reading related cognitive skills and processes of word identification. The studies in the current dissertation address this important topic.

READING DEVELOPMENT

Before children face the task of learning to read, they have already acquired spoken language. They heard spoken words and stored these phonological forms in reference to objects in their environment. In other words, through spoken language, children start to acquire representations of sounds in their language. Initially, phonological representations are fairly shallow and global (i.e., whole words). Throughout language development, however, children's phonological representations become increasingly specific, when they become aware of syllables, onsets, rimes, and phonemes, and of how these units can be combined to form words (Goswami, 2000). They acquire more words and form memory representations that include information on both meanings and phonological codes. When they learn to read, a third component is added to these word representations, that is orthography, or the written form of words.

According to Ehri (2005) four phases underlie the development of these orthographic representations. Initially, children are nonreaders in a pre-alphabetic phase of reading development. If they recognize written words, recognition is based on distinct visual features or contextual cues. From the partial alphabetic phase onwards, words start to be recognized based on the alphabetic system. As children start to acquire the first systematic letter-sound mappings, they recognize incidental written words that contain these letters. However, words are recognized based on some, not all, of the letters, and are therefore often confused with similarly spelled words. Children become full alphabetic readers when they know most grapheme-phoneme connections and rely on decoding to access complete and specific phonological codes. Orthographic representations become more specific in the final consolidated phase. As children decode more words, grapheme-phoneme connections are chunked into larger units. These units include letter clusters, onsets, rimes, syllables or entire words. During reading, the phonological codes of these units can be retrieved as a whole.

A related theory is the self-teaching hypothesis (Share, 1995). This theory describes how children acquire word-specific orthographic representations through decoding. Upon encountering new written words, children can rely on grapheme-phoneme mappings to decode the letters into phonological codes. If words have been heard before, a phonological and semantic representation might already be present in memory. Accordingly, children can access their larger phonological lexicon to recognize words and a connection can be established or strengthened between the phonological and orthographic word forms.

Both Ehri's phase theory and Share's self-teaching hypothesis describe the development of orthographic knowledge. A connection between orthographic and phonological word forms fosters fast word recognition, because words no longer have to be decoded, but can be retrieved from memory. The first process toward word identification, that is decoding letters into sounds to assemble a word's phonology will be referred to as *serial processing of words.* Processing all the letters in a word simultaneously to activate whole word phonology, rather than letter sounds, will be called *parallel processing of words*. How these reading processes underlie word identification during reading, however, is not specified in these developmental theories. Models of skilled word reading, in contrast, more explicitly describe word identification processes (e.g., Ans, Carbonnel, & Valdois, 1998; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Perry, Ziegler, & Zorzi, 2007; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). These models are not intended as models of reading development. Nevertheless, some models fit very well with the developmental transition from heavy reliance on decoding toward processing an increasing number of words in parallel. Therefore, models of the reading system provide a useful framework in studying reading development as well.

READING PROCESSES

In general, two types of models of the reading system can be distinguished, that is dual route and connectionist models. Dual route models, specifically, fit well with developmental theories. These models propose two routes through which words can be read (e.g., Ans et al., 1998; Coltheart et al., 2001; Perry et al., 2007). In the Dual Route Cascaded model (DRC; Coltheart et al., 2001), for example, a sublexical and a lexical route are distinguished. Through the nonlexical route, the letters in a word are processed serially. By applying grapheme-to-phoneme conversion rules, the word is decoded letter-by-letter into its phonological code. In the lexical route, in contrast, all letters are processed in parallel, and the word is identified as a whole through activation of its representation in the orthographic, and subsequently, the phonological lexicon. Both routes work simultaneously, but as a result of reading experience, a gradual shift can be expected from reading predominantly through the nonlexical route, when many words are decoded, toward parallel processing through the lexical route, when an increasing number of words is represented in the orthographic lexicon.

An important characteristic of dual route models (e.g., Ans et al., 1998; Coltheart et al., 2001; Perry et al., 2007), as well as theories of reading development (e.g., Ehri, 2005; Share, 1995), is that reading development is assumed to be word specific. Only if words were encountered previously, decoded successfully and thus are stored in the lexicon, can letters be processed in parallel, rather than with the less efficient serial reading strategy. Another important characteristic is that the processes underlying word identification are assumed to shift from predominantly serial processes, when most words are decoded toward a stronger involvement of parallel processes when an increasing number of words can be retrieved from the lexicon.

This difference in reading processes has been studied by looking at length effects. If words are processed through serial decoding, the speed of word identification depends on the number of letters in a word. With every additional letter that needs to be decoded, the time it takes to identify the word increases. In contrast, when letters are processed in parallel, and an orthographic word form directly activates a phonological code, reading speed becomes independent of word length. In other words, a length effect in word reading latencies indicates that most words are processed serially, whereas the absence of a length effect indicates that words are processed in parallel. Indeed, it has been shown that young beginning readers show a large length effect when reading both words and nonwords, whereas more advanced readers show length effects only in naming longer words (i.e., more than six to eight letters) and nonwords, which cannot be represented in the lexicon (e.g., Hawelka, Gagl, & Wimmer, 2010; Marinus & de Jong, 2010b; Spinelli et al., 2005; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003; Zoccolotti et al., 2005).

Both characteristics, that is word-specific representations, and a developmental shift from serial toward parallel reading processes, stand in sharp contrast to the second type of connectionist models of the reading system (e.g., Plaut et al., 1996; Seidenberg & McClelland, 1989). According to the Parallel Distributed Processing model (PDP; Plaut et al., 1996), for example, the reading system consists of interconnected sublexical orthographic, phonological, and semantic units. Word-specific knowledge is assumed not to exist. The activation of these sublexical units is determined by connection weights. These weights are shaped by the language input and come to represent spelling-sound correspondences, with stronger connections for mappings that occur more frequently in the language. Within this associative network, all letters in letter strings are always processed in parallel, but the reading system becomes more efficient when connection weights become more fine-tuned throughout development.

PHONOLOGICAL SKILLS

Studies on reading related cognitive abilities have identified phonological skills as important predictors of reading performance. It is generally accepted that phonological awareness is one of the strongest predictors of reading performance, although there is no agreement yet on whether this relation is predominantly causal (Ramus et al., 2003; Vellutino, Fletcher, Snowling, & Scanlon, 2004), or reciprocal (Castles & Coltheart, 2004; Elbro, 1996; Nation & Hulme, 2010). Phonological awareness reflects sensitivity to the phonological structure of words and the ability to identify and manipulate phonemes in spoken language. Various tasks are used to assess this skill, but all tasks mainly tap the ability to shift attention from the meaning of words to their phonological forms. The relation between phonological awareness and reading has been shown to be stronger in opaque orthographies (e.g., Ziegler et al., 2010). Although strong relations are also found in transparent orthographies, when sufficiently difficult measures are used to assess phonological awareness skills (Caravolas, Volín, & Hulme, 2005; de Jong & van der Leij, 2003; Vaessen & Blomert, 2010).

Rapid naming is a second important predictor, that has been shown to be related to reading in many languages, both concurrent and longitudinally, independent from phonological awareness and other key variables, in typically developing children, as well as children with dyslexia (e.g., Cornwall, 1992; de Jong & van der Leij, 1999; Kirby, Parrila, & Pfeiffer, 2003; Landerl & Wimmer, 2008; Lervåg, Bråten, & Hulme, 2009; Moll, Fussenegger, Willburger, & Landerl, 2009; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Vaessen & Blomert, 2010; Wolf et al., 2002; Ziegler et al., 2010). In more transparent orthographies, rapid naming has even emerged as the strongest predictor of reading fluency (de Jong & van der Leij, 2002; Landerl & Wimmer, 2008; Moll et al., 2009; Vaessen & Blomert, 2010). Rapid naming reflects the ability to quickly name a set of highly familiar stimuli, typically measured as the naming speed of objects, colors, letters, or digits in sets of 5 items presented 10 times each (Denckla & Rudel, 1976). However, it has been shown that these four tasks typically load on two factors, alphanumeric (letters and digits), and non-alphanumeric (colors and pictures) symbol naming, of which alphanumeric naming is the stronger correlate of reading performance (van den Bos, Zijlstra, & van den Broeck, 2003). It is not yet clear exactly why rapid naming is related to reading (see Kirby, Georgiou, Martinussen, & Parrila, 2010, for a review). Suggestions about the nature of the relation include factors such as speed of sequential symbol processing (Kail, Hall, & Caskey, 1999), learning of arbitrary relations between symbols and names (Manis, Seidenberg, & Doi, 1999), learning of orthographic codes (Bowers, 1995), and the ability to access and retrieve phonological representations (Wagner & Torgesen, 1987).

In short, there is abundant evidence that phonological awareness and rapid naming relate to reading skills, that is the outcome of the reading system. Less clear, however, is their relation with parameters that reflect reading processes, for example the length effect. Although there is no theoretical account of the relation between phonological awareness and the length effect, the relation could possibly be explained within the context of the self-teaching hypothesis (Share, 1995). If phonological awareness is poor, phonological recoding of letter strings might be slow and error prone. According to the self-teaching hypothesis, successful recoding is essential to establish the orthographic representations that foster fluent reading. Therefore, children with poor phonological awareness likely lag behind in the build-up of an orthographic lexicon, and thus show a continued reliance on serial processing, expressed for example in a strong sensitivity to word length.

The relation between rapid naming and reading processes is even more speculative, but Wolf and Bowers (1999) offer a potential account. They argue that rapid naming might relate to the activation of letter sounds. A word can quickly be identified if all the letters are activated within a very short timeframe. If a reader is slow in identifying letters, identification might not be fast enough for all the letters to be activated at the same time, which is necessary for the integration of individual letters into a whole word representation. As a result, orthographic representations are weak, and the reader would continue to rely on serial processing, and remain sensitive to word length.

VISUAL ATTENTION SPAN

More recently, it has been argued that the role of visual rather than phonological skills in reading development should receive more attention, stimulated by complaints of individuals with reading difficulties that letters and words move around, blur and/or merge (e.g., Stein & Walsh, 1997; Vidyasagar & Pammer, 2010). One of the most prominent visual theories is the visual attention span hypothesis. According to this hypothesis, the visual attention span, that is the number of orthographic units (e.g., letters, letter clusters or syllables) that can be processed simultaneously at a glance, is a core skill that determines reading performance, independent from phonological skills (e.g., Valdois et al., 2003; Valdois, Bosse, & Tainturier, 2004).

In contrast to phonological skills, visual attention span has been explicitly linked to reading processes. Theoretically, the visual attention span hypothesis is grounded in the Multiple-Trace Memory model, a dual route model of the reading system (MTM; Ans, Carbonnel, & Valdois, 1998; Valdois et al., 2004). In this model, two successive reading procedures are distinguished. Through the global procedure knowledge of entire words is used to process words as a whole. If a word is not identified through the global procedure, the analytic procedure is activated, and the word is read through serial activation of smaller orthographic units (i.e., syllables, letter clusters or letters). Word identification through one or the other procedure depends on the visual attention span. Given that an orthographic representation is present in the lexicon, the word can be processed in parallel if the visual attention span extends over the entire letter string. If, however, the visual attention span is too small to cover the entire word, the analytical procedure is activated and visual attention is focused successively on sublexical units. In other words, if the visual attention span is too small to cover entire words, words cannot be processed in parallel, and serial analysis remains the only available reading strategy, resulting in a strong sensitivity to word length.

Indeed, visual attention span has been shown to contribute to reading performance, independent from phonological skills in typically developing children (Bosse & Valdois, 2009), and in children with dyslexia (Bosse, Tainturier, & Valdois, 2007). In addition, there is some evidence that visual attention span is related to serial processing. Visual attention span related to the number of eye movements during reading (Hawelka & Wimmer, 2005), more specifically to the number of rightward fixations (Prado, Dubois, & Valdois, 2007). The number of eye movements can be regarded a parameter of the reading system, similar to the length effect, since the number of fixations per word indicates whether processing is serial (multiple fixations within a word) or parallel (a single fixation per word).

So far, however, the relation of visual attention span with reading has mainly been established by the research group of Valdois and colleagues (e.g., Bosse et al., 2007; Bosse & Valdois, 2009; Valdois et al., 2003; Valdois et al., 2004), for children who learn to read an opaque orthography (i.e., French or English). Also, there is still quite some debate as to the exact nature of the relation between visual attention span and reading. Researchers disagree on whether visual attention span is a purely visual skill (e.g., Lobier, Zoubrinetzky, & Valdois, 2012; Valdois, Lassus-Sangosse, & Lobier, 2012), or is mainly verbal in nature (e.g., Hawelka & Wimmer, 2008; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010).

CURRENT STUDIES

The current studies were aimed at bridging the gap between studies that focused on the development of reading processes on the one hand, and studies that examined cognitive skills that foster reading performance on the other hand. Phonological skills have been shown to predict reading performance, but it is unclear how these skills relate to reading processes. Visual attention span has recently been shown to be an additional predictor of reading abilities. Interestingly, in contrast to phonological skills, visual attention span has been explicitly linked to reading processes. However, little is known about the relevance of visual attention span as a predictor of reading skills in a more transparent orthography. In the current studies it is first examined whether visual attention span is an independent predictor of word reading fluency in Dutch. Next, it is examined how visual attention span, as well as phonological awareness and rapid naming, relate to parameters of the reading system. The final two studies address the broader question of how to identify and study the processes underlying word reading.

First, it is established whether visual attention span is a predictor of reading fluency in a more transparent orthography (Chapter 2). Two unresolved issues concerning visual attention span are addressed. It is examined whether the contribution of visual attention span to reading fluency is independent of rapid naming. Previous studies have shown that the relation is independent of phonological awareness (e.g., Bosse & Valdois, 2009), but rapid naming, another important predictor of reading performance, has not been controlled for. In addition, the relation of visual attention span with spelling performance is examined. This is the first study to address this issue. Interestingly, the relation with spelling performance can shed light on the nature of the visual attention span task. Visual attention span has been proposed to be related to the acquisition of orthographic knowledge (e.g., Bosse & Valdois, 2009; Valdois et al., 2004). Therefore, a relation with performance on a spelling task, requiring the production of correct orthographic word forms, would be implied. However, a relation with spelling performance is not expected if visual attention span indeed reflects purely visual multi-element processing of orthographic units.

Second, the relation of visual attention span with both oral and silent reading is examined (Chapter 3). The vast majority of studies on the relations between cognitive skills and reading focused on reading aloud. This is surprising, given that silent reading is actually the primary reading mode for proficient readers. The question whether differences are found between oral and silent reading is in and of itself important to address, since insights gained in oral reading are often tacitly generalized to silent reading. To date, little is known about similarities and differences between the reading modes. It has been argued that phonological processing might be more extensive in oral as compared to silent reading (e.g., Juel & Holmes, 1981; Share, 2008). Accordingly, it could be expected that phonological awareness, and possibly also rapid naming, is more strongly related to oral than to silent reading. There are no theoretical accounts on the specific relation of visual attention span with oral and silent reading. However, if phonological processes are indeed less important in silent reading, the contribution of visual attention span, which is a non-phonological predictor, could be larger.

In the other three studies, the focus shifts to the processes underlying word reading. In the third study it is examined how visual attention span, but also phonological awareness and rapid naming, relate to reading processes rather than reading outcomes (Chapter 4). As explained, within in context of the DRC model (e.g., Coltheart et al., 2001), length effects are studied as an indicator of reading processes. In the current study length effects are decomposed into an overall speed factor and the degree of serial processing to examine how reading related cognitive skills relate to these parameters of the reading system.

In the fourth study length effects are examined in more detail (Chapter 5). In addition to naming latencies, length effects have been found in children's lexical decisions (Acha & Perea, 2008; Filippo, de Luca, Judica, Spinelli, & Zoccolotti, 2006; Martens & de Jong, 2006). If length effects indeed reflect the underlying reading process, these findings would imply that a predominantly serial process underlies word identification in lexical decision. However, that interpretation would be at odds with the representation of lexical decisions in adults. Within the DRC model (Coltheart et al., 2001), lexical decisions are modeled only within the lexical route, as a search of the orthographic lexicon. If the letter string matches an entry in the lexicon, a 'yes' response is made. If the letter string is not represented in the lexicon 'no' will be the answer. Thus, irrespective of the lexical status, letter strings would always be processed in parallel through the lexical route. In the current study the nature of length effects in lexical decisions is examined. Two possible sources of independent evidence are considered, that is the effects of articulatory suppression and of neighborhood size, to determine whether a serial process indeed underlies children's lexical decisions, and thus whether length effects reliably reflect the reading process.

Finally, in the fifth study an alternative method to identify reading processes is considered (Chapter 6). De Jong (2011) argued that if all the letters in a word are processed in parallel to retrieve whole word phonology from memory, individual differences in word reading would be similar to individual differences in digit naming speed. In other words, de Jong proposed to consider the relations between digit naming and word reading to uncover underlying reading processes. If a word is processed in parallel, a high correlation is expected between reading a word and naming a single digit, because in both tasks a phonological code is retrieved from memory. If, however, a word is decoded, a stronger correlation is expected with naming multiple digits in a row, because in both tasks items are processed serially, either the letters in a word or the digits in the naming task. In line with the developmental shift from predominantly serial toward mainly parallel reading processes, de Jong indeed found that word reading correlated more strongly with naming multiple digits in Grade 1, but with naming a single digit in later grades. Interestingly, children could even be sorted into classes of serial versus parallel readers based on the correlations between word and digit naming. In the current study the method proposed by de Jong was examined with a new set of words. In addition, it was examined whether the same method could be extended to identify the processes underlying reading of nonwords. For nonwords, different models of the reading system propose different reading processes. According to the DRC model (e.g., Coltheart et al., 2001), nonwords always need to be decoded through the nonlexical route, because they can obviously not be present in the lexicon. PDP models (e.g., Plaut et al., 1996), in contrast, propose that words and nonwords are processed by the same reading system, through parallel activation of interconnected units.