How do children read words? A focus on reading processes

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Outside of a dog, a book is a man's best friend. Inside of a dog it is too dark to read.

- Groucho Marx -

Chapter 7
General Discussion

This dissertation was 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. First, the findings on reading processes and models of the reading system are summarized and reviewed. Then, the results concerning cognitive correlates of reading, that is phonological awareness, but mainly visual attention span and rapid naming, are discussed.

READING PROCESSES

It is generally accepted that children initially rely on phonological decoding to read words. With increasing reading experience, however, they become able to process letters in parallel and retrieve phonological codes from memory. Within the context of the Dual Route Cascaded model (DRC; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) this developmental change in reading processes has been studied by looking at length effects. A length effect emerges when words are identified through a serial reading process. When letters are decoded one-by-one to read a word, the speed of word identification is highly dependent on the length of a word. A length effect is not observed when words are processed in parallel, because the retrieval of phonological codes from memory is independent of word length. In the current studies length effects were further examined as a method to study reading processes. In addition, the relation between reading and digit naming was considered as an alternative method to infer reading processes.

Length effects were found in the naming latencies of second-grade beginning readers for both words and nonwords (Chapter 4). In line with the DRC model (Coltheart et al., 2001), as well as previous studies (e.g., Marinus & de Jong, 2010b; Spinelli et al., 2005; Zoccolotti et al., 2005), the results imply that these readers do not process the letter strings in parallel, but predominantly rely on serial decoding. Unexpectedly, the interaction between length and lexicality was not significant. Larger length effects would be expected for nonwords than for words, because nonwords can never be mapped onto a phonological code, and thus always require serial processing (e.g., Ans, Carbonnel, & Valdois, 1998; Coltheart et al., 2001). However, despite similar length effects, nonwords were read more slowly than words. Together, these results might suggest that the same processes underlie word and nonword reading, even though reading an unfamiliar letter string does at some point slow down activation of a phonological code.

In the same study, length effects were decomposed into an intercept and a slope. Interestingly, these factors correlated only moderately, indicating that they represent two related, but different parameters of the reading system. The slope, or the increase in reading latencies with each additional letter, represents the length effect, or the degree of serial processing. The intercept represents overall reading speed. Individual differences were found in both aspects. These findings are consistent with the developmental trends described by Spinelli et al. (2005) and Zoccolotti et al. (2005), showing that children's development in word reading is characterized by a decrease in the sensitivity to word length, and also by an increase in overall reading speed.

The study reported in Chapter 5, however, indicated that examining length effects might not be a reliable method to identify underlying reading processes. Although the prediction of length effects when the underlying reading process is known to be serial is straightforward, the reverse is not necessarily true. Interpreting length effects in terms of a serial underlying reading process might be more problematic (see also Risko, Lanthier, & Besner, 2011). For example, in connectionist models of the reading system, length effects are not ascribed to serial reading processes, but to visual and articulatory factors, or to differences in orthographic neighborhood size (e.g., Seidenberg & Plaut, 1998). Additional, independent evidence of a serial or parallel reading strategy was thus called for to test the reliability of length effects as reflecting serial reading processes. In the current study length effects were found in the lexical decisions of children, while independent evidence suggested that words were processed in parallel. The effects of neighborhood size on identification latencies indicated that children adopted a parallel lexical search, not a serial decoding strategy. In addition, parallel processing of letter strings was supported by the absence of an effect of articulatory suppression. These results indicate that length effects in and of itself do not prove that serial processes underlie word identification.

Therefore, an alternative method to study reading processes was examined. De Jong (2011) argued that the relations of discrete and serial digit naming with word reading can be used to infer underlying reading processes. If letters are processed in parallel, reading a word mirrors discrete naming of a single digit. If, however, letters are processed serially, reading a word more closely resembles naming multiple digits in a row. Indeed, in the current study, two classes of readers were identified based on these relations (Chapter 6). The majority of children read the words through a parallel retrieval process, similar to naming a digit. A second class of readers was identified, however, for whom reading a word more closely resembled serial digit naming, suggesting that word reading relied on a serial process. Surprisingly, the results were very similar for nonword reading. Importantly, when class assignments of word and nonword reading were combined, only three classes of readers were identified: children who read both words and nonwords in parallel, children who read both words and nonwords through decoding, and children who read words in parallel, but nonwords through decoding. Grade level was shown to be a good proxy of reading development, such that serial processors were almost exclusively found in Grade 2. These results seem to suggest a developmental path. With increasing reading experience, a shift seems to occur from a serial decoding strategy to identify every letter string, toward parallel activation of phonology first for words, and later on also for nonwords. Having established reading processes, length effects were examined to further support the interpretation of the classes. Indeed, length effects were found to be much larger in children for whom the reading process was shown to be serial, than in children who appeared to process the letter strings in parallel.

It should be noted that in the current study only short regular monosyllabic words were studied. A focus on this type of words fits well with the models of the reading system that were studied, as both the DRC (e.g., Coltheart et al., 2001) and PDP (e.g., Plaut et al., 1996) model reflect reading of monosyllabic words. Nevertheless, it is important to consider whether similar results can be expected for longer polysyllabic words. Two recent studies indicated that also for two- and three-syllable words, reading processes shift from serial decoding toward parallel identification, as reflected in the relations with serial and discrete rapid naming (Iwema, 2013; Protopapas, Altani, & Georgiou, 2013a). Further research is needed, however, to establish development patterns in the reading processes underlying short and longer words and nonwords. An interesting question to address is, for example, whether parallel processes are found for short nonwords before longer words, or vice versa.

In sum, two ways to identify reading processes were examined. First the focus was on length effects. A length effect in reading latencies is generally taken to indicate that words are read through serial grapheme-phoneme conversion. Current results, however, showed that length effects can also be found when phonology is activated in parallel. Thus, length effects might be an unreliable method to infer reading processes. An alternative method to establish reading processes was studied, which seems promising. Based on the relations of single word and nonword reading with serial and discrete digit naming, a distinction could be made between children who activate phonology mainly serially or in parallel.

These findings have important implications for our understanding of how children read words. Concerning word reading, results were in line with the developmental trends described in theories of reading development (i.e., Ehri 2005; Share, 1995). Younger, beginning readers process words through serial decoding, whereas older, more advanced readers process words in parallel. In general, reading processes were found to be tied to age and reading experience, such that most children who read serially attended second grade. A few serial processors, however, were also identified in Grades 3 and 5. The results might suggest that typically developing readers shift toward parallel activation of phonology relatively quickly, whereas poor readers continue to rely on serial decoding processes. Indeed, a pilot study suggested that children with dyslexia can be divided into the same classes of readers, but progress more slowly, as they continue to rely on serial decoding for words, and especially nonwords at least up to Grade 4 or 5 (van der Molen, 2012). This topic, however, clearly deserves further research.

The results for word reading are also compatible with the word-specific view of reading development, as assumed in dual route models (e.g., Coltheart et al., 2001). Words need to be decoded, until they become represented in the orthographic lexicon, at which point words can be processed in parallel. According to dual route models, however, nonwords can never be represented in the lexicon, and therefore always need to be processed mainly serially, through grapheme-phoneme conversion. Thus, the current finding that nonwords, like words, can be processed in parallel is at odds with the DRC model. The results are not fully in line with the alternative connectionist models either. According to connectionist models (e.g., Plaut et al., 1996), all letter strings are processed through the same parallel associative network of sublexical phonological and orthographic units. Thus, within a connectionist framework, it is not surprising that nonwords can also be processed in parallel. However, within this type of models, serial reading processes are difficult to interpret.

The current results suggest that a model of the reading system should include initial serial processing, as well as later parallel activation of phonology from print for all letter strings. Importantly, for most readers, nonwords were found to be read through the same parallel reading processes as words. Despite similar reading processes, however, reading latencies for nonwords were consistently found to be longer than for words. These findings might indicate that for both words and nonwords phonology is activated in parallel, but that the computation of this phonological code is faster when the code is known and stored in the phonological lexicon. To a large extent these findings could be explained within the framework of more recent connectionist dual process models (CDP^{+}: Perry, Ziegler, & Zorzi, 2007; CDP^{++}: Perry, Ziegler, & Zorzi, 2010). Similar to the DRC model, letter strings can be processed through a lexical and a nonlexical route. Similar to connectionist models, however, within the nonlexical route phonology is not activated serially, but in parallel. This distinction could explain both the similarity in reading processes and the differences in processing times found between words and nonwords. Phonology is activated in parallel for both types of letter strings, but for words phonology can be retrieved from memory, whereas for nonwords a new phonological code has to be assembled.

More difficult to explain within the context of these models, however, are the serial reading processes that were found for beginning readers. Beginning readers seem to activate phonological codes through serial grapheme-phoneme conversion. Within CDP models (Perry et al., 2007, 2010), serial processes are confined to a graphemic buffer. Graphemes in a letter string are serially connected to the onset, vowel, or coda position. Subsequently, phonology is activated in parallel. In other words, serial processes are ascribed to initial processing of letter identities and should no longer be found when all the letters in a string can be connected to their position simultaneously. Serial activation of phonological codes does not fit with this model. The current results might therefore suggest that an additional third route should be added to the model, similar to the nonlexical route in the DRC model. Early on, this route might be used to compute phonological codes for all letter strings through serial activation of grapheme-phoneme relations. With increasing reading experience, however, words can be stored in an orthographic lexicon by connecting the computed phonological codes to entries in the already established phonological lexicon. Simultaneously, readers might develop the associative network of orthography-phonology connections that allows parallel processing of nonwords. In time, the proposed third route might come to be discarded in typically developing readers, or only be used when highly atypical letter strings are read, such as very long words, or unfamiliar letter strings that do not adhere to the orthographic or phonological patterns of a language. Poor readers, in contrast, might continue to rely on this third route as a result of difficulties in building an orthographic lexicon, or a network of sublexical orthography-phonology connections.

CORRELATES OF READING

The second aim of the current dissertation was to examine visual attention span, but also phonological awareness and rapid naming, as predictors of reading. Previous studies focused mainly on the relations between these predictors and reading outcomes. In the current studies, however, it was also examined how the predictors relate to reading processes.

PHONOLOGICAL AWARENESS

Concerning phonological awareness, the results are completely in line with previous studies that identified phonological awareness as one of the main predictors of literacy skills across the board (e.g., Landerl & Wimmer, 2008; Moll, Fussenegger, Willburger, & Landerl, 2009; Nikolopoulos et al., 2006; Verhagen, Aarnoutse, & van Leeuwe, 2008, 2010). Phonological awareness was found to be a predictor of word and nonword reading fluency, of both oral and silent reading, and of spelling performance (Chapters 2, 3, and 4). Although these relations are sometimes found to be stronger in less transparent orthographies (e.g., Ziegler et al., 2010), the current results add to a growing body of research indicating that substantial long-term relations are also found in more 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).

The relation of phonological awareness with parameters of the reading system had rarely been specified (see for an exception Hawelka & Wimmer, 2005). A specific relation was found between phonological awareness and the length effect (Chapter 4). Children with stronger phonological awareness skills were able to process more words in parallel, and thus were found to be less sensitive to word length. Poorer phonological awareness, in contrast, was associated with continued reliance on serial reading processes. This relation could be interpreted within the framework of the self-teaching hypothesis. Children with poor phonological awareness likely lag behind in the buildup of an orthographic lexicon, because they fail at successfully recoding new letter strings, which is essential in establishing the orthographic representations that foster fluent reading (Share, 1995). However, given the doubts casted on the interpretation of length effects in terms of serial processes, the issue of how exactly phonological awareness affects the way in which children read words requires further research.

VISUAL ATTENTION SPAN

Recently, visual attention span has been put forward as a predictor of reading skills by the research group of Valdois and colleagues (e.g., Valdois et al., 2003; Valdois, Bosse, & Tainturier, 2004). Visual attention span has been shown to contribute to reading performance in typically developing children (Bosse & Valdois, 2009), as well as children with dyslexia (Bosse, Tainturier, & Valdois, 2007), learning to read an opaque orthography (i.e., English or French). The contribution of visual attention span was independent of phonological awareness (Bosse et al., 2007; Bosse & Valdois, 2009; Valdois et al., 2003; Valdois et al., 2004). More specifically, visual attention span was found to relate equally strongly to word and nonword reading. The relation with regular words was found to decrease, whereas the relation with irregular words remained stable across grades (Bosse & Valdois, 2009).

Based on these findings, visual attention span has been interpreted as the number of orthographic units (e.g., letters, letter clusters or syllables) that can be processed simultaneously at a glance. Theoretically, visual attention span is grounded in the Multiple-Trace Memory model (MTM; Ans, Carbonnel, & Valdois, 1998; Valdois et al., 2004). Within this model, visual attention span, as a measure of the visual attentional window, is essential in determining the efficiency of letter string processing. To allow for parallel processing of words, the word needs to be represented in the orthographic lexicon, but in addition, the visual attention span needs to cover the entire word. A visual attention span that is too small to cover entire words would lead to continued reliance on serial processing of sublexical units, and thus to slower reading speed. The specific relation of visual attention span with irregular words has been ascribed to the acquisition and establishment of orthographic knowledge. A larger visual attention span fosters the acquisition of orthographic knowledge, because all letters of a string need to be activated in parallel to establish whole word representations (e.g., Ehri, 2005; Share, 1995). Orthographic knowledge, in turn, is of specific importance in reading irregular words, more than regular words or nonwords.

The current results indicate that visual attention span is indeed an important independent predictor of reading fluency, also in a more transparent orthography (Chapters 2, 3, and 4). Importantly, visual attention span explained variance over and above phonological awareness, but also verbal short-term memory and rapid naming, two important correlates of reading that were previously not controlled for. The visual attention span task has been criticized for reflecting verbal short-term memory or rapid naming skills due to its verbal stimuli (i.e., letters) and brief exposure time (see Bosse & Valdois, 2009; Valdois et al., 2004). The current findings, however, support the claims of Valdois and colleagues, that visual attention span reflects a skill that is important in reading, over and above the aspects that might be shared with known phonological correlates of reading performance.

Visual attention span was found to relate to overall reading speed, but also to the length effect, reflecting the sensitivity to word length (Chapter 4). Keeping in mind the objections to using length effects to establish reading processes, these results appear to be in line with evidence from studies on eye movements (Hawelka & Wimmer, 2005; Prado, Dubois, & Valdois, 2007), and support the specific relation between visual attention span and reading processes as proposed within the framework of the MTM model (Ans et al., 1998). A larger visual attention span indeed fosters parallel processing of words, whereas children with a smaller visual attention span continue to rely on a serial processing strategy. Furthermore, the relation of visual attention span with nonwords was found to be equal to the relation with words (Chapters 2 and 4). Since nonwords cannot be represented in an orthographic lexicon, this finding could indicate that visual attention span also relates to variations in the size of the orthographic units that can be processed through the serial analytic procedure. Children with a larger visual attention span might, for example, be able to process letter clusters or syllables serially rather than single letters.

Some of the current findings, however, are not fully in line with the work of Valdois and colleagues. Bosse and Valdois (2009) found that the relation between visual attention span and regular word reading decreased across grades. In contrast, the study reported in Chapter 2 showed that for children learning to read Dutch, this relation was stable across grades, if not increasing. Thus, perhaps especially in languages in which the majority of the words is regular, the crucial aspect in the long-term relation of visual attention span with reading fluency might not be the acquisition of orthographic knowledge as suggested by Bosse and Valdois (2009). Rather, the key aspect could to be the amount of orthographic information that can be processed within a glance, irrespective of whether this information is mapped onto whole-word phonology through the global route or to sublexical units in the analytic procedure.

It is still widely debated whether visual attention span concerns a purely visual skill (e.g., Lobier, Zoubrinetzky, & Valdois, 2012; Valdois, Lassus-Sangosse, & Lobier, 2012) or actually reflects visual to phonological code mapping (e.g., Hawelka & Wimmer, 2008; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010). So far, the current results were mainly in line with the first interpretation. The present finding of a similar relation of visual attention span with oral and silent reading also appeared to support this interpretation (Chapter 3). It has been argued that phonological processing could be more extensive in oral as compared to silent reading (e.g., Juel & Holmes, 1981; Share, 2008). If visual attention span would reflect verbal code mapping, a stronger relation could have been expected with oral than with silent reading. A similar relation with oral and silent reading would thus support an interpretation of the task in terms of aspects that are equally important in both oral and silent reading, such as visual processing of letter strings. However, in the same study, it was found that phonological awareness related equally strongly to both oral and silent reading. This finding supports strong phonological theories of reading, which state that activation of phonology is equally important in both oral and silent reading modes (e.g., Frost, 1998; Perfetti & Hart, 2002). Consequently, an equally strong relation of visual attention span with oral and silent reading does not necessarily distinguish between the two interpretations of visual attention span.

What was found to be important in understanding the nature of visual attention span is its relation with spelling performance. This effect had not been studied previously. The current results indicated that visual attention span is a unique predictor of both orthographic knowledge and spelling performance (Chapter 2). Similar to the effect of visual attention span on reading exception words, the effect on spelling can be explained through the acquisition of orthographic knowledge, which is called upon in spelling tasks (Ans et al., 1998; Valdois et al., 2004). Orthographic knowledge is acquired when a connection is established between a word's orthographic and phonological form, which often occurs during reading (Ehri, 2005; Share, 1995). Accordingly, if the relation of visual attention span with spelling performance should be ascribed to the acquisition of orthographic knowledge, the effect should be mediated by orthographic knowledge and possibly reading fluency. However, the relation of visual attention span with spelling performance remained significant after controlling for both skills (Chapter 2).

To accommodate these findings, a slightly different interpretation of visual attention span is called for. The specific relation with spelling is difficult to understand if visual attention span is interpreted as parallel mainly visual processing of multiple orthographic units. Fluent reading clearly benefits from parallel processing of multiple elements, and this characteristic also seems to best distinguish the visual attention span task from the phonological tasks included in the studies. In spelling tasks, however, the input is a phonological rather than orthographic word form and orthography needs to be activated accurately rather than quickly. An interpretation of visual attention span purely in terms of verbal coding also seems unlikely, given that the relations of visual attention span with both reading and spelling were independent of, for example, verbal short-term memory and rapid naming, tasks which also clearly require verbal coding. Nevertheless, the visual attention span task does include letters as stimuli. Therefore, phonology needs to be activated and is thus expected to play a role in visual attention span performance.

Accordingly, an interpretation of visual attention span should probably incorporate both multi-element and verbal coding aspects of the task. It is therefore proposed that visual attention span reflects the strength of the connections between orthography and phonology. Strong orthography-phonology connections would enable processing multiple elements at the same time, which in turn fosters both reading and spelling performance, when either orthographic units can be mapped simultaneously onto phonological words forms, or the other way around, when phonological codes can simultaneously be converted into a correct orthographic word form. Different from the rapid naming task, where orthographic information remains available, and from the phonological awareness task, where there is no constraint on processing time, the visual attention span task seems to place the highest demands on orthography-phonology connections, because letters are presented only briefly, and need to be reported verbally. Only if the letters automatically activate the associated phonological codes within one glance, can the letters be reported correctly.

Taken together, the current studies have shown that visual attention span is an important predictor of reading fluency in Dutch. The relation was equally strong for both word and nonword reading fluency, and for both oral and silent reading performance. These results can be interpreted within the MTM model (Ans et al., 1998), and indicate that a larger visual attention span fosters parallel processing of multiple orthographic units, which are simultaneously mapped onto whole-word phonology, or onto sublexical phonological codes. However, visual attention span was also found to be a unique predictor of spelling performance. These results call for a slightly different interpretation of visual attention span in terms of the quality of orthography-phonology connections. If connections are strong, orthographic codes can be processed in parallel to activate phonological codes, which fosters reading fluency, but phonological codes can also be mapped in parallel onto orthographic representations, needed when one is asked to spell a word.

Similar to the DRC model (e.g., Coltheart et al., 2001), the MTM model (Ans et al., 1998) assumes that nonwords always require serial processing. Therefore, the current results of similar parallel reading processes for both words and nonwords, cannot be explained within the MTM framework. The results on visual attention span can be interpreted within the alternative model as proposed in the previous section. A large visual attention span could promote parallel processing of both words and nonwords by enabling parallel activation of phonology from print either through lexical representations or through the network of sublexical orthography-phonology connections. If the visual attention span is too small to cover entire letter strings, identification needs to proceed through the proposed third route, through serial grapheme-phoneme conversion.

RAPID NAMING

Rapid naming has been shown to be an important phonological skill predicting reading performance independent of phonological awareness (e.g., de Jong & van der Leij, 2003; Landerl & Wimmer, 2008; Moll et al., 2009; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Vaessen & Blomert, 2010; Wolf & Bowers, 1999; 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). The current results are completely in line with these findings. In children learning to read Dutch rapid naming was found to be the strongest predictor of reading fluency, independent of phonological awareness (Chapters 2, 3, and 4). Although it is generally accepted that rapid naming skills relate strongly to reading abilities, the exact nature of the relation is still widely debated (see Kirby, Georgiou, Martinussen, & Parilla, 2010, for a review). Several findings of the current studies add to this ongoing debate.

Interestingly, rapid naming related equally strongly to both word and nonword reading fluency (Chapters 2, 4, and 6). This indicates that rapid naming is related to an aspect of reading that is shared in the processing of all letter strings, irrespective of the lexical status of the string (see also Georgiou, Papadopoulos, Fella, & Parilla, 2012; Moll et al., 2009). The relation of rapid naming with spelling performance has been less clear. Some studies have shown a unique contribution to spelling (Savage, Pillay, & Melidona, 2008; Sunseth & Bowers, 2002; Verhagen et al., 2010), whereas others have indicated that rapid naming did not contribute to spelling performance over and above phonological awareness (Cornwall, 1992; Landerl & Wimmer, 2008).

The current findings indicate that rapid naming has no unique contribution to spelling performance (Chapter 2). Together, the relation of rapid naming with nonword reading, and the absence of a relation with spelling performance indicate that rapid naming likely does not reflect the learning of orthographic codes, as suggested by Bowers (1995), among others.

In addition, a difference was found in the relation of rapid naming with oral and silent reading. Rapid naming related more strongly to oral than to silent reading (Chapter 3). Since phonological awareness related equally strongly to both reading modes, the difference should probably not be ascribed to phonological processes playing a larger role in oral than in silent reading. Previously, the stronger relation of rapid naming with oral reading has been interpreted as evidence for the importance of oral production in the relation of rapid naming with reading (Georgiou, Parrila, Cui, & Papadopoulos, 2013). Both rapid naming and oral reading, but not silent reading, require articulation, or the production of verbal output. The current findings support this interpretation, which is also in line with models of speech production (e.g., Levelt, 1992). In these models, a distinction is made between lexical selection, and phonological encoding. Whereas phonological representations might be activated in both silent and oral reading, computation and articulation of a verbal code is specific to oral reading.

Together, the current findings indicate that rapid naming reflects an aspect of reading that is shared in the processing of all letter strings, irrespective of length or lexicality, but that is more important in oral than in silent reading, and is not important in spelling. However, it was also found in the current studies that it is important to take into account the format of both rapid naming and reading tasks (Chapter 6). The results described so far concerned serial rapid naming. This can be considered the standard version of the task, as is it used in the majority of studies. Although serial rapid naming appears to be a strong predictor of reading performance, the task has been criticized for being too similar to reading tasks to be a true predictor of reading performance, such that ‘the seemingly simple task of naming a series of familiar items as quickly as possible appears to invoke a microcosm of the later developing, more elaborated reading circuit’ (Norton & Wolf, 2012, p. 429). In other words, it has been suggested that the relation between rapid naming and reading performance is overestimated since the relation should be ascribed solely to similar task demands, such as the left-to-right and downward reading direction.

In support of this idea it has been found that serial rapid naming is a stronger predictor of reading outcomes than discrete naming (Wolf & Bowers, 1999). The current results, however, indicate that the relation of rapid naming with reading depends on the format of both the rapid naming and the reading task. The results support the conclusions of de Jong (2011). Serial naming is the stronger predictor of performance on a serial reading task, but discrete naming was the stronger correlate of single word reading. Unlike Logan and Schatschneider (in press), who found that discrete naming did not predict reading performance over and above serial naming, the current results show that when discrete word reading is considered, discrete naming is a stronger predictor than serial naming.

It should be noted, however, that most reading tasks are of a serial, rather than discrete nature. In addition, it has been shown that serial naming is of specific importance in distinguishing between poor and average readers. Although poor readers were slower than typical readers in naming single items, the most important difference is that typically developing readers showed a clear advantage of naming items in a serial over a discrete format, whereas the opposite is true for children and adults with dyslexia (Jones, Branigan, & Kelly, 2009; Zoccolotti et al., 2013). For them, naming or reading in a serial format resulted in similar or slower naming latencies than discrete naming of single items.

The question remains, however, what kind of processes are measured with a serial naming task. Protopapas, Altani, and Georgiou (2013b) showed that the relation with reading should not be ascribed merely to the left-to-right and downward reading direction, since a backward version of the rapid naming task, in which the reading direction was right-to-left and upward, correlated equally strongly with reading. In addition, in the current studies, a relation was found between serial naming and single word and nonword reading, for which the influence of a reading direction would be small if present at all. However, the relation between serial naming and single word reading was found to be especially important in young beginning readers (Chapter 6). These readers do not activate phonological codes for single words in parallel, but rather rely on a serial sublexical reading strategy. Serial naming thus seems to capture the intraword serial processes found in beginning readers. Similarly, rapid naming has been shown to be a specific predictor of reading performance in readers with dyslexia (e.g., Wolf & Bowers, 1999). These poor readers experience difficulties especially in decoding single words such that they process single items serially rather than in parallel. Furthermore, this impairment at the word level could produce the severe difficulty of poor readers in dealing with multiple items as shown by Jones et al. (2009) and Zoccolotti et al. (2013), as well as in dealing with the multiple task requirements intrinsic to reading (see de Luca, Pontillo, Primativo, Spinelli, & Zoccolotti, 2013). Typically developing readers, however, seem able to process single words in parallel relatively early, since the majority of children in Grade 2 was already able to process words in parallel (Chapter 6). Accordingly, serial naming no longer contributed to single word reading. In contrast, serial naming does continue to relate to performance on a serial reading task (e.g., de Jong, 2011). To explain this relation Protopapas et al. (2013a), suggest that serial rapid naming relates mainly to interword serial processes, and that a shift occurs from separately processing individual items, toward processing multiple items simultaneously. Taken together, these findings suggest that rapid naming relates to both intraword and interword serial processes. In beginning readers, who do not yet process single words in parallel, individual differences would be found at both levels of serial processing. With increasing reading experience, however, phonological codes for single items can be activated in parallel and individual differences on a serial reading task might become more strongly related to interword serial processes in terms of the number of items, rather than the number of letters, that can be processed in parallel.

The relation between serial naming and the reading process was also examined in Chapter 4. It was found that rapid naming, different from phonological awareness and visual attention span, related to individual differences in overall reading speed, but not the length effect. In other words, in that study, rapid naming did not relate to the degree of intraword serial processing in words and nonwords. This finding is difficult to interpret. On the one hand, the majority of the second grade children included in the study probably processed the words in parallel (as shown in Chapter 6). On the other hand, significant length effects were found at the group level (Chapter 4). These findings could challenge the suggestion of a relation between serial naming and intraword serial processes. Alternatively, these findings could reflect the fact that length effects might not be a reliable method to infer reading processes. Further research is needed to sort out this issue.

Taken together, rapid naming was shown to relate to both word and nonword reading at both the intra- and interword level. In addition, rapid naming related to oral more than to silent reading, and did not relate to spelling performance. Accordingly, rapid naming might reflect the ability to access or compute a phonological representation and the corresponding verbal output. Whereas phonological representations might be activated in both silent and oral reading, computation of verbal output is specific to oral reading. Moreover, verbal output is required in both word and nonword reading, but not in spelling.

Unlike visual attention span, rapid naming has not been tied to a specific model of the reading system. Rapid naming could be expected to play a role mainly in the phonological aspects of the reading process. In terms of the proposed triple route model, rapid naming could relate to the access to phonological codes and computation of verbal output, common to all three routes. In other words, rapid naming might reflect how quickly phonological codes and verbal output can be retrieved from the lexicon, or computed through the network of sublexical orthography-phonology connections, or serial grapheme-phoneme conversion. Although this interpretation is highly speculative, it has recently been shown that the degree of automaticity in translating visual input to phonological codes is critical in understanding poor reading performance, in addition to phonological processing per se (see Pan, Yan, Laubrock, Shu, & Kliegl, 2013).

PRACTICAL IMPLICATIONS AND FUTURE DIRECTIONS

Taken together, phonological awareness, but especially rapid naming and visual attention span were found to be independent predictors of reading fluency in a more transparent orthography. Not only were the effects found to be independent, the cognitive skills were also shown to have a different relation with reading performance, reading processes and spelling. Rapid naming was proposed to reflect mainly the access to phonological codes and the computation of verbal output. Visual attention span appeared to reflect the quality of the orthography-phonology relations in terms of the amount of information that could be processed simultaneously.

These current results hold some practical implications for the assessment of reading abilities, most importantly for diagnosing dyslexia. It is common practice to assess (mostly oral) reading, spelling, phonological awareness and rapid naming. However, concerning rapid naming, results indicate that this skill is only related to reading, not to spelling. More specifically, rapid naming is the strongest predictor of oral reading, but its relation with the more dominant silent reading mode is much weaker. Phonological awareness, in contrast, was found to relate to both reading and spelling. Moreover, the relation with both oral and silent reading was the same. Interestingly, the same was found for visual attention span. In other words, phonological awareness and visual attention span seem to be two independent predictors of literacy skills that together could provide useful information in the diagnosis of dyslexia. Rapid naming, in contrast, seems to be a strong predictor of oral reading skills, but provides less information when silent reading or spelling skills are examined.

In the current studies, word reading in children was examined with a specific focus on reading processes. A few topics clearly deserve further research. It was shown that a gradual shift occurs from serial toward parallel activation of phonology from print. This development in reading processes, however, cannot be captured in existing models of the reading system. A new model of reading processes is thus called for. Furthermore, serial processes seem to be of specific importance in explaining the relation between rapid naming and reading. The nature of this particularly strong relation is still widely debated. Both tasks clearly require serial processes. An important similarity in serial processes across tasks is the need to activate multiple items, either one-by-one or simultaneously. There are, however, also important differences across tasks. In a rapid naming task, the previous item needs to be deactivated or even inhibited to foster processing of the current item. In contrast, reading is most successful when the items that have been serially identified (i.e., letters in a word, or words in text) remain active in memory while processing the current item. Finally, the relation between serial processing in reading and visual attention span is poorly understood. Visual attention span seems to relate to the amount of information that can be processed in parallel, such that a large visual attention span is needed to allow parallel processing of entire words. Less clear, however, is the relation between a smaller visual attention span and serial processing of sublexical units. A small visual attention span restricts letter string identification to the analytic procedure. Within the analytic procedure, however, it is proposed that sublexical units can vary from single letters, to letter clusters or syllables. However, at what point children move, for instance, from letter-by-letter to syllable-by-syllable processing, and how this transition might be affected by visual attention span is still unknown.