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READING DEVELOPMENT DURING ELEMENTARY SCHOOL YEARS

EVIDENCE FROM EYE MOVEMENTS

by

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READING DEVELOPMENT DURING ELEMENTARY SCHOOL YEARS:
Evidence from Eye Movements

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ABSTRACT

The present dissertation examined reading development during elementary school years by means of eye movement tracking. Three different but related issues in this field were assessed. First of all, the development of parafoveal processing skills in reading was investigated. Second, it was assessed whether and to what extent sublexical units such as syllables and morphemes are used in processing Finnish words and whether the use of these sublexical units changes as a function of reading proficiency. Finally, the developmental trend in the speed of visual information extraction during reading was examined.

With regard to parafoveal processing skills, it was shown that 2nd graders extract letter identity information approx. 5 characters to the right of fixation, 4th graders approx. 7 characters to the right of fixation, and 6th graders and adults approx. 9 characters to the right of fixation. Furthermore, it was shown that all age groups extract more parafoveal information within compound words than across adjective-noun pairs of similar length. In compounds, parafoveal word information can be extracted in parallel with foveal word information, if the compound in question is of high frequency. With regard to the use of sublexical units in Finnish word processing, it was shown that less proficient 2nd graders use both syllables and morphemes in the course of lexical access. More proficient 2nd graders as well as older readers seem to process words more holistically. Finally, it was shown that 60 ms is enough for 4th graders and adults to extract visual information from both 4-letter and 8-letter words, whereas 2nd graders clearly needed more than 60 ms to extract all information from 8-letter words for processing to proceed smoothly.

The present dissertation demonstrates that Finnish 2nd graders develop their reading skills rapidly and are already at an adult level in some aspects of reading. This is not to say that there are no differences between less proficient (e.g., 2nd graders) and more proficient readers (e.g., adults) but in some respects it seems that the visual system used in extracting information from the text is matured by the 2nd grade. Furthermore, the present dissertation demonstrates that the allocation of attention in reading depends much on textual properties such as word frequency and whether words are spatially unified (as in compounds) or not. This flexibility of the attentional system naturally needs to be captured in word processing models. Finally, individual differences within age groups are quite substantial but it seems that by the end of the 2nd grade practically all Finnish children have reached a reasonable level of reading proficiency.

CONTENTS

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Turku, April 2011.

Tuomo Häikiö

LIST OF ORIGINAL PUBLICATIONS

The dissertation is based on five original articles. The articles are referred to in the text by the following Roman numerals:

I Häikiö, T., Bertram, R., Hyönä, J., & Niemi, P. (2009). Development of the letter identity span in reading: Evidence from the eye movement moving window paradigm. *Journal of Experimental Child Psychology, 102,* 167-181.*

II Häikiö, T., Bertram, R., & Hyönä, J. (2010). Development of parafoveal processing within and across words in reading: Evidence from the boundary paradigm. *The Quarterly Journal of Experimental Psychology, 63,* 1982-1998.**

III Häikiö, T., Bertram, R., & Hyönä, J. (2011). The development of whole-word representations in compound word processing: Evidence from eye fixation patterns of elementary school children. *Applied Psycholinguistics, 32*, 533-551.***

IV Häikiö, T., Bertram, R., & Hyönä, J. (Submitted). The role of syllables in word recognition among 2nd grade children: An eye movement study.

V Blythe, H.I, Häikiö, T., Bertram, R., Liversedge, S.P, & Hyönä, J. (2011). Reading disappearing text: Why do children refixate words? *Vision Research, 51,* 84-92.*

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1. INTRODUCTION

The present dissertation deals with reading development of children during elementary school years. When children enter the elementary school, they already possess phonological, semantic and syntactic knowledge about language and words. In other words, they can already produce spoken words and construct sentences out of them. Furthermore, they can understand spoken words and sentences other people produce. What they lack is orthographic knowledge, that is, knowledge about words in written form. Naturally, it is crucial for every beginning reader to acquire this information in order to be able to read. Because children do know a lot about language and how it works, teachers make use of this knowledge in the process of teaching children to read. In other words, teachers are trying to make a link between the phonological, semantic and syntactic knowledge children already possess and the orthographic knowledge that needs to be acquired in order to be able to read.

Initially, teaching concentrates on the correspondence between graphemes and phonemes, that is, children are taught which particular written symbol corresponds to which particular sound. Once the correspondence between letters and sounds has developed to a certain extent, children are able to read most words by sounding out the individual letters. After this, the focus in teaching moves towards bigger units within words. In Finnish, after the children have familiarized themselves with grapheme-phoneme correspondences, the main focus is on syllables. In early reading instruction words are hyphenated at syllable level. Furthermore, when words are read aloud, children are encouraged to clap hands at each syllable. Initially, one may assume that these syllables have stronger phonological than orthographic representations, but it can also be assumed that as children become more proficient readers, they start to develop stable orthographic representations for syllable-sized units as well, which will allow them to increase their reading speed. One may assume that this development goes hand in hand with the development of the perceptual span in reading (the area from which useful information is extracted). Furthermore, one may also assume that this development is manifested in the speed with which readers extract letters and words from written text. However, the exact nature of the development in all these areas during elementary school years has not been studied to a large extent.

In the present dissertation, the aim was to extend the knowledge on how fast children make progress in the above-mentioned aspects of reading. To this end, eye movements were registered while elementary school children were engaged in reading. Furthermore, adults were tested in most of the studies to compare children's reading performance with skilled adult readers. Eye movement registration in connection with specific paradigms allowed us to get a picture of the development of Finnish children's reading skills during the elementary school years. In all studies, elementary school children read either single sentences or short stories on a computer screen. We assumed that as children receive more practice and education in reading they become qualitatively different readers. How and when changes are taking place was the main subject of investigation. In order to investigate the changes taking place during elementary school years, we tested readers of varying ages in all the studies presented in the dissertation. Since it would have been too time-consuming to test elementary school children of each grade (1st to 6th in Finland), we opted to test children from the 2nd, 4th, and 6th grade. In order to further investigate reading performance as a function of reading skill, we assessed fast and slow readers of the same age groups separately.

We set out to investigate three different issues that – as pointed out quickly above already – are important in the development of reading. First, we were interested in the development of parafoveal processing skills in reading (studies I and II). Study I specifically focuses on the development of the perceptual span in reading. The perceptual span can be defined as the amount of information that a reader is able to extract during one single eye fixation. We focused on one particular aspect of the perceptual span, namely the amount of letters a reader may identify at any given fixation, that is, the letter identity span. It may be assumed that this span becomes larger with increasing reading proficiency, but how exactly it develops over the elementary school years and whether there are differences within one and the same class is less clear. Study II investigated whether the extent with which parafoveal processing takes place depends on whether two words appear in a noun phrase with a space in between them or whether they appear in a concatenated compound. It also investigates whether the concatenation of words in a compound drives the system towards processing these words in a parallel fashion. In order to investigate these issues, we used eye movement contingent display change paradigms. Change paradigms are paradigms in which the amount of information around the fixation is manipulated. These paradigms allow one to determine from how large area specific information can be extracted during one single fixation and whether information is processed serially or in parallel.

Second, we assessed whether and to what extent sublexical units such as syllables and morphemes are used in processing Finnish words and whether the use of these sublexical units changes as a function of reading proficiency. It has been suggested by some theories of reading development (e.g., Ehri, 1987, 1989; Frith, 1985) that – as reading proficiency grows – readers start to process words via sublexical units and eventually even via whole-word units. In contrast, the psycholinguistic grain size theory (Ziegler & Goswami, 2005) holds that in shallow orthographic languages such as Finnish the very consistent grapheme-phoneme correspondence may yield a processing system that is less dependent on larger-sized units beyond the letter. In our studies, we investigated whether reading development in Finnish is more in line with the position taken by Ehri (1987, 1989) and Frith (1985) or by Ziegler and Goswami (2005). In the studies examining the use of syllables (Study IV) and morphemes (Study III), participants read sentences without being exposed to changes taking place on screen (as in the change paradigms mentioned above and below).

Finally, we investigated the developmental trend in the speed of visual information extraction during reading. Previous studies (e.g., Blythe, Liversedge, Joseph, White, & Rayner, 2009; Liversedge, Rayner, White, Vergilino-Perez, Findlay, & Kentridge, 2004; Rayner, Liversedge, White, & Vergilino-Perez, 2003; Rayner, Liversedge, & White, 2006) have shown that for native English adults words only have to be presented for about 40-60 ms in order for reading to proceed smoothly (that is, in these studies words literally disappeared after having fixated them for 40-60 ms and that is why this experimental paradigm was coined the disappearing text paradigm). In other words, only 40-60 ms is enough to transfer lexical information from paper or computer screen to the visual cortex. Blythe et al. (2009) demonstrated that, when it comes to 6-letter words, even for 7-year-old children 40-57 ms is enough to extract all visual information required for reading to proceed smoothly. In Study V, we investigated by means of the disappearing text paradigm what happens when 2nd and 4th grade children are presented with longer words of 8 letters. We speculated on forehand that it may well be that the visual processing system of younger children is not swift enough to extract all 8 letters within 60 ms and hence reading would be disrupted and/or it may be the case that they would have to regress extensively to the longer words in order to obtain a second visual sample. We examined whether there is a developmental trend in the speed of visual information extraction from the 2nd to the 4th grade as well as how the children's performance compares to adult performance.

Above, I have given a brief sketch on what this dissertation is about. In the following, I will extend on some of the central issues that are dealt with in this dissertation. In section 1.1, I will discuss some basic characteristics of adults' eye movements during word processing as well as some basic factors that affect the speed with which they process them. In section 1.2, I will outline the development of eye movement and word processing behavior. Since English is the most studied language in reading development and since Finnish is different from English in many ways, I will – in section 1.3 – describe language differences between these two languages and the possible implications of these differences for word processing behavior. In section 1.4, I will provide more specific information related to eye movements and the employed eye movement paradigms. In section 1.5, the final section of the introduction, I will come back to the aims of the present dissertation in greater detail. Then, in section 2, I will present an extensive summary of all 5 studies included in this dissertation. Finally, in section 3, I will discuss the findings of all studies and will outline their theoretical implications as well as their implications for future research and practice.

1.1. Word processing

In the following, I will first discuss a number of basic factors that influence word processing speed (section 1.1.1). Then I will turn to the role of sublexical units in word processing (section 1.1.2), after which I will address word processing issues in relation to eye movements (section 1.1.3).

1.1.1 Basic factors that influence word processing speed

There are many factors that affect the speed of word processing. One of these factors is word length – longer words are read slower than short words, and this is partly due to the fact that longer words usually attract more fixations than shorter words (e.g., Rayner & McConkie, 1976; see Rayner, 1998, for a review). Furthermore, it has been shown that the more frequent a word is, the faster it can be processed (e.g., Gerhand & Barry, 1998; Inhoff & Rayner, 1986), also reflected in a larger number of fixations for infrequent words than frequent words (e.g., Rayner, Sereno, & Raney, 1996). Another factor that affects processing speed is the age of acquisition of words (AoA); the earlier a word has been acquired, the faster it can be processed (e.g., Gerhand & Barry, 1998). Moreover, also a word's family size (i.e., the number of derived and compound words beginning with the same word stem) affects its processing speed; the larger the family size is, the faster the word can be processed (e.g., Schreuder & Baayen, 1997). Frequency, family size, and AoA are all indexing the familiarity of the word, and the rule of thumb seems to be that the more familiar the word is, the faster it is processed. One could say that the representations of more familiar words become stronger due to which they have lower activation thresholds and are more quickly available. Another 'big' factor affecting word processing speed is predictability. More precisely, if a word is predictable from the previous context, it is easier to process (Balota, Pollatsek, & Rayner, 1985) and more likely to be skipped (Drieghe, 2008). Finally, many other word characteristics, such as phonological and orthographic neighborhood density, concreteness and imageability, as well as meaningfulness (see Balota, Yap, & Cortese, 2006, for a review), also affect the speed of word processing.

However, since they are not within the scope of the current dissertation, I will not discuss them in detail.

Not only word characteristics but also text characteristics affect the speed of processing. Among other things, the clarity of visual information affects processing speed. For example, reduced quality of print slows down reading speed (e.g., Morrison & Inhoff, 1981). Also, if the text as a whole is conceptually hard, processing speed decreases (Jacobson & Dodwell, 1979; Rayner & Pollatsek, 1989). However, this is connected more to the integration of words in the text level representation than to word-level processing, which is the focus of the present dissertation.

Naturally, also reader's characteristics affect processing speed. For instance, if a reader is familiar with the topic in question, the text is conceptually easier and thus faster to process. In addition, reading fluency increases with increased reading experience with experienced adult readers reading faster than inexperienced ones (e.g., Cipielewski & Stanovich, 1992; Stanovich, 1986) and with older children and adults typically reading faster than younger children. It has been shown that with increasing reading proficiency readers make longer and fewer saccades, and their fixations become shorter and fewer (Lefton, Nagle, Johnson, & Fisher, 1979; see Rayner, 1998, for a review). I will cover reading proficiency and its development in more detail in section 1.2.

1.1.2 The role of sublexical units in word processing

Above, I already indicated that there is ample evidence that factors such as frequency, word length and predictability affect word processing speed. Not surprisingly, these factors play an important role in both serial processing models of reading such as E-Z Reader (e.g., Pollatsek, Reichle, & Rayner, 2006) as well as in parallel processing models of reading such as SWIFT (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005) or Glenmore (Reilly & Radach, 2003, 2006). However, both types of models basically assume that printed words are mapped upon whole-word orthographic access representations without prelexical activation of lower-level sublexical units (but see Reichle, Rayner, & Pollatsek, 2003, for an attempt).[1] Nevertheless, there is evidence showing that the lower-level units may mediate lexical access. Most notably there is evidence that both syllables (e.g., Ashby & Martin, 2008; Colé, Magnan, & Grainger, 1999; González & Valle, 2000; Maïonchi-Pino, Magnan, & Écalle, 2009; Yap & Balota, 2009) and morphemes (e.g., Bertram, Laine, & Virkkala, 2000; Bertram, & Hyönä, 2003; Burani, Marcolini, De Luca, & Zoccolotti, 2008; Carlisle, 2000; Frost, Deutch, & Forster, 2000; Giraudo & Grainger, 2001; Rabin & Deacon, 2008) are used in the course of lexical access.

However, the evidence for syllables and morphemes as prelexical access units is not unequivocal, at least not for adults. Thus whereas Ferrand, Segui and Humpreys (1997) found syllable priming effects in English and in French, Schiller (2000) failed to replicate these findings in English as well as Brand, Rey, and Peereman (2003) failed to replicate these findings in French. Also, even though several studies reported that increasing the number of syllables comes with slower response latencies, the same studies showed that this number of syllables effect disappears (Ferrand & New,

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[1] In the present dissertation, I will focus on SWIFT (Engbert et al., 2005) and E-Z Reader (Pollatsek et al., 2006) because these models are the most worked out eye movement guidance models of reading.

2003; Jared & Seidenberg, 1990) or is attenuated (Yap & Balota, 2009) in words of high frequency.

Similarly, even though there is a wealth of evidence showing that morphemes are functional processing units in the course of multimorphemic word processing (e.g., Hyönä & Pollatsek, 1998; Laudanna, Burani, & Cermele, 1994), there is evidence suggesting that morphemic units are activated postlexically only after lexical representations have been activated (e.g., Giraudo & Grainger, 2001). In addition, several studies indicate that the role of morphemic units is attenuated or neglectable under certain circumstances. As for syllables, morphological effects are harder to obtain for high-frequency multimorphemic words (see e.g., Alegre & Gordon, 1999; Kuperman, Bertram, & Baayen, 2009). In addition, at least in Finnish they are harder to obtain for morphologically complex words that are relatively short (Bertram & Hyönä, 2003). As I will point out in section 1.2, it may be expected that syllabic and morphological effects are more pervasive for children who are not at the end point of reading development.

1.1.3 Word processing issues in relation to eye movements

It has been shown that in reading eyes make jumps (i.e., saccades) that are followed by fixations, during which eyes are stationary (e.g., Huey, 1908; see Rayner, 1998, for a review). Because of saccadic suppression, virtually no information relevant for reading is extracted during saccades. For adults reading English, saccades are on average 7-8 characters long, and 10-15 % of all saccades are regressive. Most saccades land near the word centers (e.g., McConkie, Kerr, Reddix, & Zola, 1988; Rayner, 1979; Vitu, McConkie, Kerr, & O'Regan, 2001) and rarely on the spaces between words (e.g., Abrams & Zuber, 1972). Adults tend to fixate most of the words, but short and predictable words (e.g., *the*, *is*) are often skipped (e.g., Carpenter & Just, 1983; Rayner & McConkie, 1976; see Rayner, 1998, for a review). While long words may draw more than one fixation, shorter words are usually fixated just once (when they are not skipped). On average, each fixation lasts for 200-250 ms. As mentioned above, it has been shown that 40-60 ms is enough for extracting all necessary visual information from a word, even for children reading short words (e.g., Blythe et al., 2009; Liversedge et al., 2004; Rayner, Liversedge, et al., 2003; Rayner et al., 2006). After these first 40-60 ms of visual information extraction, the extracted information is further processed in the word recognition system and during this period saccades are planned in order to bring new textual information in sharp visual focus as well.

There are some other basic principles connected to the visual field in reading that need to be discussed. For adults (e.g., McConkie & Rayner, 1975; Rayner, 1986; see Rayner, 1998, for a review), it has been shown that the area from which readers extract useful information (global perceptual span) extends from the beginning of the currently fixated word to approx. 14-15 characters to the right of fixation. The global perceptual span comprises the foveal and parafoveal area. The foveal area is the area of high visual acuity and extends approx. 6-8 characters around the fixation whereas the parafoveal area comprises the remainder of the global perceptual span. Outside this area (i.e., periphery) no information relevant to reading is extracted. It needs to be noted that the global perceptual span is physiologically symmetric, but in reading the effective vision is asymmetric incorporating more 'new' than 'old' text information (i.e., it extends more to the right than to the left in languages such as English and Finnish). In other words, the global perceptual span extends – at least in languages such as English – approximately to the beginning of the currently fixated word (but no further than 4 characters to the left of fixation) and 14-15 characters to the right of fixation.

Different kinds of information are extracted from different areas within the global perceptual span. For adults, it has been shown that word length information is extracted furthest away from fixations (e.g., McConkie & Rayner, 1975; Rayner, 1986). This is done with the help of spaces between the words, and this information is used in programming saccades to upcoming words. From a smaller area, readers extract information about letter features and letter identities. It has been shown (e.g., Balota et al., 1985; Pollatsek, Lesch, Morris, & Rayner, 1992) that letter feature information (i.e., the shapes of the letters) is extracted from a larger area than letter identity information (i.e., the exact identities of the letters). For children, the letter identity span has not been studied, that is, as far as I know, Study I of this dissertation is the first study that deals with this issue. At any rate, it seems that adult readers do extract information from the parafoveal word as well as the currently fixated word, and the more information is extracted from the parafoveal word, the shorter processing times are required when the word is eventually fixated (see Rayner, 1998, for a review). As mentioned earlier, in case of short words, all processing can be done during the fixation of a previous word, in which case the word can be skipped altogether. The amount of parafoveal processing is also connected to the characteristics of the currently fixated word (e.g., Henderson & Ferreira, 1990; Rayner et al., 1996; White, 2008; White, Rayner, & Liversedge, 2005). For example, it has been shown that in case of high foveal load (Henderson & Ferreira, 1990), less information is extracted from the parafovea. In other words, when the currently fixated word is hard to process (for any of the reasons explained above), there is less time to process information from the parafovea than when the foveal word is easy to process. Furthermore, the same holds for the parafoveal word – the harder the parafoveal word is to process, the less information is extracted from it while fixating the foveal word (e.g., Inhoff & Rayner, 1986).

The question whether words are processed serially or can be processed in parallel is a hotly debated issue within the field of eye movement behavior in reading. Models of serial processing (e.g., E-Z Reader; Reichle, Pollatsek, Fisher, & Rayner, 1998) posit that attention is restricted to one word at a time. Saccadic programming to the next word may begin earlier though, namely after the first stage of lexical identification (a stage in which a reader familiarizes herself with the word that is fixated) has been completed. If a word is completely identified, before the saccadic program has been determinated, attention will be shifted to the next word. From this point in time onwards until the moment the saccade to the next word is executed, characteristics of the upcoming word will be ‘pre-processed’. Subsequently, the amount of pre-processing will affect the processing times of the parafoveal word when it is eventually fixated. One of the implications of the model is that characteristics of the parafoveal word cannot affect processing times of the foveal word, since these characteristics only come into play when the saccadic program is on its way already. For this reason, any effect of parafoveal word characteristics on foveal processing times, the so-coined parafoveal-on-foveal effects (PoF effects; Kennedy, 2000), has been taken as evidence against serial processing models of reading. However, it needs to be noted that the latest versions of the E-Z Reader model (e.g., Pollatsek et al., 2006) include a pre-attentive phase, during which parafoveal low-level information can be processed in parallel with foveal information. This could account for some PoF effects. However, one could claim that PoF effects are more naturally explained by models of parallel processing (e.g., SWIFT; Engbert et al., 2005), which do not need to rely on a pre-attentive phase to account for PoF effects, but hold that attention may spread simultaneously over multiple (up to four) words. By virtue of shared attention across words, properties of upcoming words may affect processing times of foveally fixated words.

So far, the evidence for PoF effects is inconclusive. There is some evidence suggesting they may exist (e.g., Kennedy, 2000; Kennedy, Pynte, & Ducrot, 2002; Kliegl, Risse, & Laubrock, 2007; White, 2008), but the majority of reading experiments suggest that the characteristics of parafoveal words do not affect processing times of currently fixated words (e.g., Altarriba, Kambe, Pollatsek, & Rayner, 2001; Hyönä, Bertram, & Pollatsek, 2004; Pollatsek et al., 1992), or that if they do, it is in fact due to mislocated fixations (Drieghe, Rayner, & Pollatsek, 2008). The mislocated fixations account suggests that PoF effects are caused by fixations that were intended for the parafoveal word but due to an error in the saccadic programming the saccade has landed on the foveal word instead while attention is directed to the parafoveal word. Drieghe et al. (2008) demonstrated that when the trials with fixations landing on the last letters of the foveal word were excluded, there were no PoF effects to be found. However, as yet it is unclear whether the mislocated fixations account would offer an explanation for the few orthographic and even rarer semantic PoF effects that have been found (e.g., Inhoff, Radach, Starr, & Greenberg, 2000; Kliegl, Nuthmann, & Engbert, 2006)

In our studies, we extended the issue of serial vs. parallel word processing to the processing of concatenated compound words. Compound words are a special class of multimorphemic words that actually consist of two or more words (e.g., fire/fly). In English, compounds can be either concatenated (i.e., unspaced), hyphenated or spatially separated (i.e., spaced), whereas in Finnish they are always hyphenated or concatenated. This means that the constituents of Finnish compounds are both spatially and lexically unified, lexical unification referring to the tight lexical connection that constituents of a compound word have. In adjective-noun word pairs, for example, one can usually replace the adjective to a synonym without changing the meaning of the word pair whereas for compounds this is usually not possible, that is, changing one constituent also changes the meaning of a compound word, or creates a novel compound altogether. The tight unification of constituents is also reflected in the fact that the constituents of compounds are processed in a different fashion than separate words. For instance, more information gets extracted from the second constituent of a concatenated compound word than a separate word, even if word length is controlled for (e.g., Hyönä et al., 2004; Juhasz, Pollatsek, Hyönä, Drieghe, & Rayner, 2009). For example, Hyönä et al. (2004) reported substantially larger amount of parafoveal processing in Finnish compounds than is usual between spatially separated words. Juhasz et al. (2009) showed the same for English compounds. Since there is more parafoveal processing within compound words, it is possible that one might find PoF effects for compounds. So far, there has been no solid evidence for PoF effects in compounds, even for adults (e.g., Hyönä et al., 2004; Pollatsek & Hyönä, 2005; White, Bertram, & Hyönä, 2008). However, in the White et al. (2008) study there was a numerical trend for PoF effect in gaze duration (i.e., first pass reading time) on the 1st constituent. In other compound studies (Hyönä et al., 2004; Juhasz et al., 2009; Pollatsek & Hyönä, 2005), there have also been numerical trends for PoF effect, even though these effects did not turn out to be significant.

As discussed above, spatial unification affects word processing to a great extent. However, there is one more type of unification that needs to be discussed briefly, namely linguistic unification. Juhasz et al. (2009) found a larger than usual amount of parafoveal processing for separate words when they used adjective-noun word pairs. They argued that the fact that adjectives are almost exclusively followed by nouns makes them syntactically more predictable, leading to a larger amount of parafoveal processing. This ties in nicely with the larger than usual amount of parafoveal processing within compounds than separate words, and therefore, it seems that when the two units are spatially and/or linguistically unified, more parafoveal information gets extracted than when there is no unification.

1.2 Development of word processing

So far, I have focused on issues related to adults' word processing. In this section, I will discuss the development of word processing during elementary school years. Before going into development of word processing skills in detail, it should first be pointed out that the progress children are able to make in learning to read words in the beginning phases is tightly connected to their phonological awareness (e.g., Goswami & Bryant, 1990; Liberman, 1973; Liberman, Shankweiler, Fischer, & Carter, 1974). Phonological awareness can be described as a skill allowing one to analyze, categorize and compare sounds in spoken language (Nation, 2008). This skill is a precursor to reading in alphabetic languages because in the early phases of reading the sounds in a word need to be separated and distinguished from one another in order to map them on their visual counterparts. Therefore, it should come as no surprise that in several studies it has been found that phonological awareness is a good predictor of learning to read (e.g., Goswami & Bryant, 1990).

As in section 1.1, I have divided the remainder of section 1.2 into three subsections. In 1.2.1, I will briefly cover a number of basic factors that influence word processing speed. Then, in section 1.2.2, I will discuss the role of sublexical units in word processing. Finally, I will address word processing issues in relation to eye movements (section 1.2.3).

1.2.1 Basic factors that influence word processing speed

As for adults, it has been shown that children read short words faster than long words (e.g., Hyönä & Olson, 1995), as well as frequent words faster than infrequent words (e.g., Burani, Marcolini, & Stella, 2002; Hyönä & Olson, 1995). However, the size of the word length effect decreases as a function of age (e.g., Zoccolotti, De Luca, Di Pace, Gasperini, Judica, & Spinelli, 2005), suggesting the developing readers move towards using larger processing units. I will discuss this issue in more detail in section 1.2.2. It has also been shown that words that are acquired early are read faster than later acquired words (Coltheart, Laxon, & Keating, 1988). As for adults, one could say that as words become more familiar to children, their representations become stronger due to which they have lower activation thresholds and can be more quickly accessed. Furthermore, the predictability of a word given the preceding sentence context affects word processing times of children. For example, Joseph, Liversedge, Blythe, White, Gathercole, and Rayner (2008) showed that at least 10-year-old children processed words that were anomalous in relation to the preceding context more slowly than words that were plausibly related to the preceding context. All in all, it seems that the same factors are playing a role in children's word processing behavior as the ones that play a role in adults' word processing behavior.

1.2.2 The role of sublexical units in word processing

In section 1.1.2, I noted that syllabic and morphological effects may be more pervasive for children than for adults. I will discuss the specific findings that seem to support this claim later in this section. First, however, I will discuss some theories on reading development (e.g., Frith's stage model, 1985) which propose that children go through different stages in their reading development and that at some point in their development they make use of sublexical units such as the syllable and the morpheme. According to Frith (1985), during the first stage (*logographic stage*) children learn to associate certain words with certain concepts on the basis of logographic features. In other words, at this stage children employ sight reading strategies and recognize certain words on the basis of visual features, such as font and color. Strictly speaking, this stage does not involve real reading. After this stage, children gradually move to the next stage, namely the *alphabetic stage*. At this stage, children start to learn the principle of the alphabet and correspondence between certain phonemes and graphemes, and their reading proceeds on a letter-by-letter basis. Ehri (1987, 1989) further divides this stage into the *partial-alphabetic phase* and *full-alphabetic phase*. In the former phase, children are aware of some sound-letter relationships whereas in the latter phase they are able to fully use correspondences between phonemes and graphemes when reading words. Ehri (1987, 1989) has proposed that as readers become more proficient, they do not stick to pure letter-by-letter strategies. Instead, in the *consolidated-alphabetic phase*, they have learnt that certain letter clusters reoccur in the given language, such as common syllables or morphemes. These orthographic patterns are stored in memory and can be retrieved as whole units diminishing the need of letter-by-letter reading. One may wonder how children extract units like syllables and morphemes from longer letter sequences. One possibility is that – since they have (implicitly) learned about the orthotactic regularities in their language – they use letter co-occurrence information to detect sublexical boundaries. For instance, they may detect bigram troughs in words, which means that the frequency of a certain bigram is lower than that of the preceeding and following bigram. Given that such troughs typically appear at sublexical boundaries (Seidenberg, 1987; Seidenberg & McClelland, 1989), they may signal syllable or morpheme boundaries due to which syllabic or morphemic information can be readily extracted. Finally, when children have developed into reasonably proficient readers, they may have entered the *automatic phase*, where readers are thought to recognize at least familiar words via whole-word orthographic representations (Ehri, 1987, 1989). It should be mentioned though that readers that have advanced to a certain stage may also employ strategies involved in earlier stages. This is especially necessary if whole-word units or sublexical units are not all that familiar, a situation that generally speaking is more likely for children than for adults.

The lack of (stable) orthographic whole-word representations would – as I speculated in section 1.1.2 – make it is easier to find syllable and morpheme effects for children than for adults.[2] That is, one may assume that lexical access to multisyllabic or multimorphemic words is more often mediated via the sublexical units for children than for adults. This indeed seems to be the case. When it comes to syllables, Maïonchi-Pino et al. (2009) found syllable compatibility effects for French 1st, 3rd, and 5th grade children in a letter cluster detection task. That is, these children had to respond whether a letter cluster such as 'BA' presented on a computer screen appeared at the beginning of a subsequently presented word such as 'BALANCE' or

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[2] It should be noted here that children must have phonological whole-word representations already, otherwise they would not know the words. What is under development are the orthographic representations, a memory trace for a combination of graphemes that form words.

'BALCON' and it turned out that they were faster to respond when the letter cluster comprised the first syllable (as in BA-LANCE) than when it did not (as in BAL-CON). This effect extended to both high and low frequency syllables for 5th graders whereas for the younger children it was restricted to high frequency syllables. This result demonstrates that less developed readers do not use syllables as access units unless the syllables are relatively frequent whereas for the more proficient readers (in this case the 5th graders) even low frequency syllables are functional units in word processing. In Spanish, a high frequency first syllable facilitates beginning readers' word recognition (González & Valle, 2000) whereas for adults its effect is inhibitory (Conrad, Carreiras, Tamm & Jacobs, 2009). This can be explained by the fact that children typically have a smaller lexicon due to which even high frequency syllables do not activate that many lexical candidates, so that possibly inhibitory competition effects do not occur. In contrast, the larger lexicons of adults would introduce greater competition between lexical candidates starting with the same syllable which would in turn slow down the processing of one of these candidates to a great extent. At any rate, these studies demonstrate that the syllable is a functional unit in word processing but that its importance changes as the readers become more proficient. In the present dissertation, it was examined at which point in time there is a change from reliance on syllables as functional processing units towards more whole-word based strategies.

With regard to morphemes, there is evidence that children start using morphology in reading morphologically complex words already during the 1st grade. For instance, Colé, Royer, Hilton, Marec, and Gombert (2005) reported that good 1st graders read morphologically complex words faster when they were preceded by morphologically related primes than orthographic or unrelated control words. Furthermore, it has been shown (Feldman, Rueckl, DiLiberto, Pastizzo, & Vellutino, 2002; Rabin & Deacon, 2008) that 1st to 5th grade children often generate words in a fragment completion task (e.g., need after being presented with ne_ _) that are morphologically related to words they were exposed to in a study phase (e.g., needs, needy). When they were exposed to orthographically related words in the study phase (e.g., needle) they more often generated words that did not correspond to the initial letters of the word (e.g., neat). Also other studies show that morphological units are effectively used in word processing during elementary school years (e.g., Anglin, 1993; Burani et al., 2002; Carlisle & Stone, 2005; Elbro & Arnbak, 1996). There are also a number of studies indicating that – as I indicated before – the role of morphology is modulated by factors such as word frequency. For instance, Bertram et al. (2000) showed that both Finnish 3rd and 6th graders performed much better in a word definition task on low-frequency derived than low-frequency monomorphemic words, but this difference was attenuated to a great extent in the high-frequency range. Similarly, Burani et al. (2008) showed that skilled 6th grade and adult Italians named morphological pseudowords much faster than simple ones, but familiar morphologically complex and monomorphemic words were named equally fast. Younger 2nd and 3rd grade children were faster in the morphological conditions in both cases, however. Taken together, this indicates that access to familiar morphologically complex words is mediated via morphemes to a much smaller extent for high-frequency than for novel or low-frequency words, at least for children of higher grades and adults.

Taken these findings together, it seems that elementary school children make use of morphemes when processing morphologically complex words from the 1st grade onwards. Even rather proficient 6th grade readers make use of morphemic units in case of low-frequency words. However, it seems also clear that for more frequent morphologically complex words access is not (often) mediated via morphemes. We assume that during elementary school years, children develop orthographic whole-word representations by which they access words directly. When during the elementary school years the development of such whole-word representations takes place is one of the topics of the present dissertation. That is, in this dissertation we examined the developmental shift from accessing compounds words via constituents towards processing them as wholes.

There is one model that seems not completely compatible with the idea that Finnish readers develop larger-sized access units than the letter. That is, the psycholinguistic grain size theory of Ziegler and Goswami (2005) proposes that in orthographically shallow languages like Finnish there is little need to develop larger-sized access units. More precisely, it is thought that in such languages the very consistent correspondences between graphemes and phonemes can be used to mediate lexical access. In contrast, for languages with a deep orthography (e.g., English) where the grapheme-phoneme correspondence is less consistent there is a need to develop larger-sized access units in order to circumvent the problems that may arise from a clash between orthographic and phonological representations. However, it needs to be noted that the psycholinguistic grain size theory is not absolutistic in nature. That is, it is not propagated by this theory that shallow languages never develop larger-sized access units. However, the extent with which this happens is thought to be less than in case of languages with a deep orthography. I will come back to language differences between Finnish and English in section 1.3.

1.2.3 Word processing issues in relation to eye movements

Once children have learned to read to some extent, their reading can be examined by means of eye movements, just as for adults. However, research on eye movements of children during reading has been relatively sparse, most likely due to the fact that testing children with the old eye movement equipment has been rather cumbersome. Despite this, a number of eye movement studies on reading development have occurred and with the recent development of high-tech eye tracking equipment, new studies have started to emerge (e.g., Blythe et al., 2009; Joseph, Liversedge, Blythe, White, & Rayner, 2009). All of these studies will be covered below.

As mentioned above, it has been shown that as reading becomes more proficient, readers make fewer fixations of shorter duration and at the same time their saccades become longer and fewer (e.g., Buswell, 1922; Lefton et al., 1979; McConkie, Zola, Grimes, Kerr, Bryant, & Wolff, 1991; Rayner, 1985; Taylor, 1965). Whereas for 1st graders the average fixation durations are 300-450 ms, 6th graders’ fixation durations (230-270 ms) are already close to those of adults (200-250 ms). While adults normally fixate short words only once, McConkie et al. (1991) showed that 1st grade children refixate 5-letter words 57% of the time. With regard to saccades, 1st graders make 23-34 % regressive saccades whereas for 6th graders this is 21-24 %. Even though children show more variability in their eye movements than adults, their landing positions are close to the word centers, as for adults (McConkie et al., 1991). Furthermore, it seems that even for 7-year old children 40-57 ms of presentation duration is enough to extract the visual information required to read a 6-letter word, which is the same as for adults (Blythe et al., 2009). As noted before, in the current dissertation we explored whether the lack of a difference between young children and adults in the speed of visual information extraction is modulated by word length, or, to be more precise, whether the lack of a difference is still to be observed for words that are longer than 6 letters. At any rate, the development in reading skills is clearly reflected in the decrease of fixation durations and the increase of saccade length during the elementary school years.

The final issue that needs to be discussed is the development of parafoveal processing skills during elementary school years. Until this dissertation, the only systematic study on this issue has been conducted by Rayner (1986). He showed that when reading skills improve, the perceptual span does as well. That is, the amount of information extracted during a single fixation grows with increasing reading proficiency. Moreover, it seems that information extraction is asymmetric already after one year of reading instruction. Rayner focused on two specific components of the perceptual span, namely the word length span and the letter feature span. He showed that both the word length span (the area from which word length information is extracted) and the letter feature span (the area from which letter feature information is extracted) are smaller for 2nd graders than older readers but that during the elementary school years both spans reach the same size as those of adults. More specifically, while the word length span of the 2nd and 4th graders is approx. 11 characters to the right of the fixation, for 6th graders and adults it is approx. 14-15 characters. Furthermore, 2nd graders' letter feature span is approx. 7 characters to the right of the fixation, whereas it is approx. 11-12 characters for 4th graders, 6th graders, and adults. The current dissertation extends on these findings by focusing on one component of the perceptual span that wasn't studied by Rayner, namely the development of the letter identity span, the area from which letter identity information is extracted.

1.3 Differences between Finnish and English

Above, I have briefly mentioned that differences between languages may also cause differences in word processing between languages. It needs to be noted that even though the majority of reading research has been conducted with English-speaking participants, English is – because of its deep orthography – actually quite an exceptional language. As explained above, in a deep orthography there is no consistent relationship between graphemes and phonemes and in English this is especially the case for the vowels. That is, most vowel graphemes correspond to more than one phoneme and in order to determine the right phonemic variant an English reader has to consider the preceding and subsequent letters. In other words, the context of a specific vowel grapheme is important in determining the specific phoneme to which it corresponds. In order to deal with this problem, English children have to learn many larger-sized letter clusters, which may or may not correspond to syllables and morphemes. Since this is not a trivial effort, it is understandable that English reading development is delayed in comparison to reading development in more shallow orthographies (e.g., Goswami, Gombert, & De Barrera, 1998; Seymour, Aro, & Erskine, 2003; Share & Levin, 1999). Finnish is on the other side of the continuum in that it has a very shallow orthography. In fact, in Finnish grapheme-phoneme correspondence is nearly perfect, meaning that virtually all graphemes correspond to one and the same phoneme (the only exceptions being velar nasal 'ng' and gemination at word boundaries with certain letter combinations, e.g. 'ota se' 'take it' being pronounced *otasse*). Because of this, Finnish children learn to read relatively fast compared to learners in other orthographies (Seymour et al., 2003). For example, it has been shown that Finnish 1st graders with reading difficulties are already reading at the same level as normal Danish 2nd graders tested half a year later (Lundberg, Frost, & Petersen, 1988; Poskiparta, Niemi, & Vauras, 1999).

Another feature that sets Finnish apart from the majority of other languages is its morphological productivity. In Finnish there are no prepositions as in English, but instead cases are marked by inflectional suffixes and attached to noun stems. In addition, possessive suffixes can be attached to noun stems as well as question and stress particles. Because the inflections can be chained, any noun can have in principle as many as 2,000 inflectional forms; a verb may even appear in 13,000 different variants (Karlsson & Koskenniemi, 1985). Furthermore, compounding is a very productive word formation process in Finnish, even more productive than in Dutch (see Moscoso del Prado Martin, Bertram, Häikiö, Schreuder, & Baayen, 2004). Because compound words are always concatenated (or hyphenated) in Finnish (in English constituent boundaries are often marked with a space), they can be quite long. Because of this enormous morphological productivity, it may be assumed that Finnish readers encounter new word formations on a daily basis. This automatically entails that they have to rely on morphemic units in accessing many of the complex word formations anyway, simply because they see them for the first time. The morphological productivity of Finnish in comparison to English also assures that on average words are considerably longer in Finnish than English.

Finally, with respect to syllables, it needs to be noted that syllable boundaries are extremely clear in Finnish, much clearer than in English. For example, in Finnish there are no ambisyllabic segments, which refers to a segment that belongs to two syllables (e.g., ceiling, in which l is both the final segment of the first syllable and the initial consonant of the second syllable; Trammell, 1993). Instead, multisyllabic words can always be divided in clear syllables by using rules of Finnish syllabification. In addition, in Finnish reading instruction syllables are considered to be important units in learning to read fluently during the 1st and 2nd grade. For example, words are hyphenated at syllable boundaries in 1st graders' ABC books and this practice continues to some extent until the end of the 2nd grade. Furthermore, when reading aloud, each syllable is accentuated with hand claps in the early 1st grade. In English reading instruction, phonics are used instead of focusing on syllables. This means that children are being taught relationships between letter or letter clusters and sounds. Due to the inconsistency of the grapheme-phoneme correspondence in English, the same sounds can be written in multiple ways, and the same written letters can be pronounced in multiple ways depending on the surrounding letter context. While letter clusters used in phonics teaching may coincide with syllables, they often do not, and sometimes can correspond to whole words. Taken these facts together, it might be the case that syllables are more consistently used as processing units in Finnish than in English, where bigger units and other letter clusters than syllables may be used to a larger extent.

1.4 Methodology and eye movements paradigms

Eye tracking was used in all of the studies of the present dissertation.[3] The main advantage of eye tracking is that one can assess normal silent reading in a relatively unobtrusive manner. Because participants can read sentences or even longer texts in their own pace, this resembles normal reading more than other tasks like lexical decision or self-paced reading. In lexical decision experiments (e.g., Balota & Chumbley, 1984; Becker, 1979; James, 1975), participants see one string of letters at

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[3] For readers not familiar with this kind of research, it may be beneficial to first read the aims of the studies presented in section 1.5 before continuing with the methodological issues.

a time and they have to respond whether this string is a real word or not by pressing a button as quickly as possible. While the lexical decision task reveals some aspects of word processing, it does not resemble real reading since there is just one (non)word to be seen at a time. In self-paced reading (e.g., Ferreira & Henderson, 1990; Just, Carpenter, & Woolley, 1982), participants read sentences or longer texts, but proceed in the text word by word by means of pressing a button. The main problem is that there is no possibility to regress to earlier parts of the text, and the fact that they have to press button after each word means that the task is, again, not normal reading. Eye tracking, on the other hand, makes it possible to assess on-line processing on word level in normal reading quite precisely, since the current systems record eye positions at 1000 Hz with such high spatial resolution that it is possible to say which letters have been fixated on millisecond-level.

In each study, eye movements were recorded with an EyeLink eye tracker manufactured by SR Research Ltd. (Mississauga, Ontario, Canada). In Study I, we used exclusively EyeLink II whereas in Studies III, IV, and V we used a newer version, EyeLink1000. In Study II, both systems were employed. Both eye trackers are infrared video-based tracking systems combined with hyperacuity image processing with a spatial resolution capability of 0.2 degrees. For EyeLink II, the eye movement cameras are mounted on a headband. Two infrared LEDs for illuminating each eye are placed next to the eye movement cameras. The headband weighs 450 g in total. The cameras sample pupil location and pupil size at the rate of 500 Hz. Recording is performed by placing the camera and the two infrared light sources 4-6 cm away from the eye. Head position with respect to the computer screen is tracked with the help of a head-tracking camera mounted on the center of the headband at the level of the forehead. Four LEDs are attached to the corners of the computer screen, which are viewed by the head-tracking camera, once the participant sits directly facing the screen. Possible head motion is detected as movements of the four LEDs and is compensated for on-line from the eye position records. Furthermore, a chin rest was used to minimize head movements in studies conducted with EyeLink II. For EyeLink 1000, a remote table-mounted model was used. An infrared LED for illuminating the right eye is positioned next to the eye movement camera. The camera samples pupil location, pupil size, and corneal reflection at the rate of 1000 Hz. Recording is performed by placing the camera and the infrared light source approximately 50 cm away from the eye. A chin-and-forehead rest was used to minimize head movements.

Above, I have mentioned that eye tracking is a relatively unobtrusive method. It is not necessarily completely unobtrusive, since – as in our studies – participants may wear a helmet with mounted eye tracking cameras and/or rest their head on a chin rest. This naturally makes the experimental settings different from usual circumstances in normal reading. However, in the present dissertation we used paradigms where it is extremely important to have high spatial and temporal resolution, and with eye tracking equipment that allows free head movement without helmets and chin rests it is practically impossible to use the paradigms employed in the present dissertation, since their spatial and temporal resolutions are sub-optimal for our purposes (at least at the time of testing – with the current development of the eye tracking equipment the situation is changing to allow free head movement without helmets and chin rests).

In Study I, participants read short stories about animals. In the remainder of the studies, participants read single sentences that were not topically connected to the other sentences. In Studies II-V, each sentence contained a pre-defined target word which was matched with another word on basis of several lexical–statistical properties such as word frequency. These target words were used for the word level analyses reported in section 2. In all of the studies participants read silently at their own pace. Every now and then, the participants were asked either to paraphrase the sentence they had just read or to respond to yes/no questions regarding the previous sentence to ensure they were paying attention to what they were reading. In Studies III and IV, the participants read single sentences without changes taking place on screen. However, in Studies I, II, and V, eye movement contingent display change techniques were employed. In other words, there were different types of changes taking place on the screen in these studies. In the following, I will briefly go over these paradigms.

In Study I, the moving window paradigm developed by McConkie and Rayner (1975) was used to assess the letter identity span (i.e., the area from which letter identity information is extracted). With this technique one can assess the different components of the global perceptual span (e.g., McConkie & Rayner, 1975; Rayner, 1986). In this technique, there is an experimenter-defined window around the current fixation, which moves in synchrony with the eyes. Inside this window, the text is shown intact whereas the text outside the window is mutilated (see Figure 1). Since the window moves in synchrony with the eyes, the reader always sees a fixed amount of intact text. In the baseline condition, the whole text is intact. The basic assumption is that reading with a window will be disrupted, when the window becomes smaller than the global perceptual span (or any component of it). To examine the letter identity span with the moving window technique, one needs to withhold the letter identity information outside the window. Moreover, word length and letter feature information needs to be preserved outside the window so that one can be sure that the performance is affected by withholding the letter identity information and nothing else. Therefore, word spacing needs to be intact, and the letters outside the window need to be replaced with visually similar letters (i.e., letters that share the basic shape of the correct letters while not being identical). To this end, round letter such as *o* are replaced with *c*, while ascenders need to be replaced with other ascenders (e.g., *h* replaced with *b*) and descenders with other descenders (e.g., *j* replaced with *y*).

```
Baseline, fixation N:   An example of the moving window
                             *

Baseline, fixation N+1: An example of the moving window
                                       *

Window, fixation N:     An example ct bka nculmy mlubxm
                             *

Window, fixation N+1:   Vu avewqia of the movlmy wlubxm
                                       *
```

Figure 1. An example of a baseline condition and a symmetrical 11-character window around the center of fixation in the moving window paradigm on two consecutive fixations.

In Study II, the boundary paradigm (Rayner, 1975) was used to assess how much parafoveal information is extracted from the word right of the fixated word when it is either a separate word or the second constituent of a compound word. In a way, the boundary paradigm is a special case of the moving window paradigm but there is only one change that takes place during each trial. As long as the participant's eye has not crossed an invisible experimenter-defined boundary, a certain word is displayed in an incorrect form but when the participant crosses the boundary, the word is changed to its correct form during the saccade (see Figure 2). As in Study I, the letters were replaced with visually similar letters. If readers extract parafoveal information from the following word, reading should be disrupted when there is a change in comparison to the baseline condition in which there is no change (i.e., the parafoveal word is intact throughout the trial).

```
Baseline, word N-1:  How are words|changed in this paradigm?
                              *

Baseline, word N:    How are words|changed in this paradigm?
                                     *

Change, word N-1:    How are words|cheuyab in this paradigm?
                              *

Change, word N:      How are words|changed in this paradigm?
                                     *
```

Figure 2. An example of a baseline condition and a change condition in the boundary paradigm on two consecutive fixations. Vertical line marks the invisible boundary.

In Study V, the disappearing text paradigm was employed to assess the speed of information extraction for short 4-letter and long 8-letter words. In this paradigm, each word disappears after it has been fixated for an experimenter-defined interval, usually 60 ms. The word does not reappear on the screen until it is exited to fixate another word, which in turn then disappears after the interval (see Figure 3). The idea behind this paradigm is that if the experimenter-defined interval is long enough for extracting the visual information, there should be no disruption by the disappearing text neither on an overall level (slower reading performance) nor in the need to reread the word (as reflected by regressions back to disappeared words). If the 60 ms exposure is not long enough for extracting all information to read a word smoothly, one may observe that word reading times become longer and/or that readers are required to make more regressions to words they already have fixated in order to obtain a second visual sample.

There are certain issues that need to be discussed when it comes to using eye movement contingent display change techniques. Naturally, there are no changes taking place in normal reading. However, making changes during saccades or even during fixations as in the disappearing text paradigm seems to be a very useful way to get insight into same basic aspects of eye movement behavior that otherwise may be difficult to acquire. For instance, the disappearing text paradigm seems to offer a reliable way to assess the amount of time needed for extracting visual information in reading and manipulating information in the parafovea is to my mind the most direct way to test how much and what kind of information is extracted from that area.

```
1. After 0 ms:  In the disappearing text paradigm...
                *

1. After 60 ms:    the disappearing text paradigm...
                *

2. After 0 ms:  In the disappearing text paradigm...
                    *

2. After 60 ms: In     disappearing text paradigm...
                    *

3. After 0 ms:  In the disappearing text paradigm...
                          *

3. After 60 ms: In the              text paradigm...
                          *

4. After 0 ms:  In the              text paradigm...
                               *

4. After 60 ms: In the              text paradigm...
                               *
```

Figure 3. An example of the disappearing text condition on four consecutive fixations. Note that the word ‘disappearing’ does not reappear on the screen at the onset of the 4th fixation since the empty location that has replaced the word is being fixated and the word area has not been exited yet.

One may argue that the changes taking place onscreen may disrupt reading per se. However, it needs to be noted that readers do not become aware of changes taking place onscreen as long as they take place less than 6 ms after the end of the saccade (McConkie & Loschky, 2002). It does happen that changes sometimes take place after this 6 ms, but in the present dissertation, in the vast majority of the trials the change took place within this 6 ms. Furthermore, the trials in which the change took place too late were excluded from the analyses (14% of trials on average). Therefore, in the trials that were analyzed, the changes took place early enough for readers not to become aware of them. Furthermore, since changes are made during saccades (apart from Study V, where the whole idea behind the experiment is to test the impact of text disappearing while reading), and because vision is suppressed during saccades, changes can usually be made so that participants do not become aware of them. When asked after the experiment whether they had noticed any changes, most of the participants indicated that they were not aware of the changes at all or noticed only a few of them. I think that all in all it is safe to say that the eye movement contingent display change techniques are a reliable way to assess parafoveal processing.

Finally, with respect to the dependent measures that were used, I would like to point out that apart from the usual eye movement measures such as gaze duration and first fixation duration, selective regression path duration (SRPD) was used in many of the studies as well. This is a measure where all fixations on the target word before it is exited to the right for the first time are summed together. Because in all of the studies where SRPD was used the sentence frames were identical up until word N+1 apart from the actual target word, any differences in SRPD between two conditions must be due to the target words. Furthermore, SRPD is a measure that captures both 1st and 2nd pass reading. In that sense one could claim that it not only captures processing efforts that are related to lexical access, but also processes that are related to how easily a word can be integrated into the sentence. Total fixation duration (TFD) also captures 1st and 2nd pass reading, but as the sentence frames are not identical up to the end of the sentences, one cannot be sure that the differences in TFD are purely caused by target words. Because of this, SRPD seems to be a good measure to consider in eye movement reading research and to me it seems that in future research it should be more widely considered.

1.5 Aims of the studies

In the present dissertation, the aim was to examine the development in word processing skills from three different angles. In studies I and II, the development of parafoveal processing skills was assessed. In studies III and IV, we examined to what extent lexical access is mediated through sublexical units and how this develops during elementary school years. Finally, in Study V, the development of the speed of visual information extraction was assessed. I will present the aims of each individual study in more detail below.

In Study I, the aim was to examine how many letters can be identified during a single fixation, and to assess how this letter identity span (i.e., the area from which letter identity information can be extracted) changes as a function of reading skill. To this end, Finnish 2nd, 4th, and 6th grade children as well as adults were tested with the moving window paradigm (McConkie & Rayner, 1975). We hypothesized that in the beginning stages of reading (i.e., 2nd grade) the readers allocate most of their attention to the currently fixated word yielding a rather small letter identity span whereas for the more proficient 4th and 6th graders we expected that also information from the parafoveal word is extracted yielding a larger letter identity span. We hypothesized that the letter identity span develops throughout the elementary school years.

One open question was whether the development of the letter identity span comes to its summit in the 6th grade. In order to investigate this issue, we also tested an adult subject group. If the summit is to be reached at the 6th grade, there would be no difference in the effect of window size between 6th graders and adults. Furthermore, we also wanted to investigate whether there were differences within each reader group. We hypothesized that the more proficient (i.e., faster) readers of each age group would have larger letter identity spans than the less proficient (i.e., slower) readers. We even thought that it may be possible that more proficient 4th graders may have similar letter identity spans as adults.

In Study II, we set out to examine whether readers extract more parafoveal information from the second word within a compound word while the first word is being fixated than from a noun in a length-matched adjective-noun word pair while the adjective is being fixated (perhaps it is good to note that words within a compound are often referred to as constituents). Furthermore, we were interested to see whether the constituents of a compound word can be processed in parallel or whether processing constituents is strictly serial. Finally, we assessed the developmental trends with respect to these issues during the elementary school years by testing Finnish 2nd, 4th, and 6th grade children as well as adults. The paradigm used to investigate these issues was the boundary paradigm (Rayner, 1975), which I explained above.

We hypothesized that more information is extracted within words than across words. However, we also expected that this difference in information extraction may interact with reading proficiency, such that larger differences would be found for more proficient readers. We thought that for 2nd graders it might be the case the by virtue of a limited perceptual span (Rayner, 1986) and extra processing resources needed for currently fixated words, it is possible that they do not extract more information from the second word within a compound than from the noun in an adjective-noun sequence. This expectation was rather intuitive though, since it may as well be possible that 2nd graders would allocate attention over both words in a compound, given that it initially may not be completely clear that there are two words within a compound. To find evidence for parallel processing of constituents, we expected that readers would need to be quite proficient, since it seemed to us that processing more than one word at the time requires efficient and automatized word processing skills. In other words, whereas we expected to find evidence for parallel processing for 6th graders and adults (also given the fact that we selected early-acquired high frequency compounds), we certainly did not expect to find any evidence for this for younger readers.

In Study III, the aim was to examine whether morphemes are used in accessing bimorphemic compound words. To this end, we tested Finnish 2nd, 4th, and 6th grade children, who were engaged in reading sentences with embedded target compound words that were either concatenated (e.g., *autopeli* ‘racing game’) or hyphenated (e.g., *ulko-ovi* ‘front door’). In Finnish, compounds are always hyphenated when the first constituent ends with the same vowel as the second constituent begins. Because both hyphenated and concatenated compounds were relatively short, it could be assumed that they would roughly fall within foveal vision. It was hypothesized that if morphemes are used in lexical access, reading hyphenated words should be faster since the hyphen marks the morpheme boundary and thus makes it easier to detect individual morphemes. We expected that 2nd graders would benefit from hyphens under the assumption that they access morphologically complex words via their constituents. Given that the compounds were relatively short, we expected that at least 6th graders would access them in a more holistic fashion and that therefore hyphenation would be disruptive to processing speed. Finally, because differences in reading proficiency within age groups are substantial, we also included this factor (as indexed by global reading speed) to assess if it modulates the way short compounds were accessed.

In Study IV, we aimed to examine the use of syllables in lexical access by Finnish 2nd graders. To this end, participants read sentences containing target words that had either an implicit or explicit syllable boundary cue. In Experiment 1, we used the hyphen as an explicit syllable boundary cue (e.g., kah-vi ‘cof-fee’). In post-hoc analyses of Experiment 1 as well as in the main analyses of Experiments 2 and 3, we used the bigram trough (bigram of lower frequency than that of preceding and following bigram) at the syllable boundary as an implicit syllable structure cue. It was hypothesized that if syllables are used in lexical access, cues signaling the syllable boundary should facilitate processing. On the other hand, we considered it to be possible that a more explicit cue like the hyphen would be disruptive in itself, since we thought it may require visuo-spatial and attentional adaptation. In this case the possible facilitative syllable boundary signaling effect of the hyphen may be diminished or turned around altogether. However, if syllables are used in lexical access, the least one may expect is a facilitative effect of an implicit syllable boundary cue, such as the bigram trough. Because with growing reading proficiency the use of syllables is likely to diminish, we included reading proficiency as a factor. This time we did not include children from different grades, but instead used 2nd graders who were in the beginning of the 2nd school year (early 2nd graders) as well as 2nd graders who were at the end of their 2nd school year (late 2nd graders). Both groups were tested against adults who may be considered as highly proficient Finnish readers.

Finally, in Study V, we examined the speed with which Finnish children can extract visual information necessary for word processing. To also assess the development in this area, we tested 2nd and 4th graders as well as adults. The paradigm we used was the disappearing text paradigm. In this paradigm, each word disappears after fixating for a pre-designed interval (60 ms in the present study) and reappears only after it has been exited (either to a word at the left or at the right). Since a previous study has shown that relatively short words can be dealt with without problems when presented for 60 ms, we decided to manipulate word length by including relatively short words of 4 letters as well as relatively long words of 8 letters. We expected that for long words especially the 2nd graders would be affected by the disappearing text manipulation. That is, we expected that for them the 60 ms would not be enough to extract all the information needed to process an 8-letter word without problems. Hence, we expected that they would be either slowed down in their reading and/or would have an increased need to regress back to the 8-letter target word to acquire a second visual sample.

2. SUMMARIES OF THE STUDIES

In Table 1, the results of each study are summarized. In the following, I will go through each study in more detail.

Table 1. Summaries of the Studies.

Study	Purpose & Method	Participants	Main results	Conclusions
Study I	Investigating letter identity span and its development by means of moving window paradigm	2nd, 4th, and 6th graders, adults	2nd graders' span 5 characters to the right of fixation; 4th graders' span 7 characters; 6th graders' and adults' span 9 characters. Slower readers' span smaller than faster readers' span.	Letter identity span develops throughout the elementary school; less proficient readers allocate most of their attention to currently fixated word.
Study II	Investigating extent and nature of parafoveal information extraction in long compounds and adjective-noun sequences by means of boundary paradigm	2nd, 4th, and 6th graders, adults	For each group more parafoveal processing within than across words; for each group parallel processing of constituents in long high-frequency compounds.	Attentional allocation is more extensive and more parallel in case of linguistically and spatially unified words, even for 2nd graders; attention in reading is flexible in nature.
Study III	Investigating use of morphemes in short compound processing by pitting hyphenated against concatenated compounds. Target words embedded in sentences in standard reading paradigm.	2nd, 4th, and 6th graders	Fast 2nd graders as well as all 4th and 6th graders faster in processing short concatenated than short hyphenated compounds; for less proficient 2nd graders, fixation durations were shorter in hyphenated compounds.	Slow 2nd graders benefit from morpheme boundary cue, indicating that they access all compounds via morphemes; more proficient readers access concatenated compounds via whole-word representations.
Study IV	Investigating use of syllables in multisyllabic word processing by manipulating syllable boundary cues (hyphen, bigram trough). Target words embedded in sentences in standard reading paradigm.	Early and late 2nd graders, adults	Hyphenation disruptive to early 2nd graders; bigram troughs facilitative for early and less proficient late 2nd graders; no effect of bigram trough for more proficient 2nd graders and adults.	Less proficient 2nd graders use syllables in lexical access; more proficient readers process short multisyllabic words in holistic fashion; hyphenation enforces readers to focus on smaller units.
Study V	Investigating speed of visual information extraction in short and long words by means of disappearing text paradigm	2nd, and 4th graders, adults	Disappearing text did not disrupt 4th graders and adults' reading; for 2nd graders no disruption for short words but more regressions back to long words.	2nd graders need a second visual sample of long words due to relatively small perceptual span; the larger perceptual span allows 4th graders and adults to extract visual information of long words with one fixation.

Study I

In Study I, the moving window paradigm (McConkie & Rayner, 1975) was employed to examine how many letters can be identified during a single fixation. Furthermore, it was assessed whether this letter identity span changes as a function of reading skill. To this end, Finnish 2nd, 4th, and 6th grade children (8, 10, and 12 years of age, respectively) as well as adults were tested. In the moving window paradigm, participants always see a fixed amount of uncorrupted text around the fixation through a window that is pre-defined by the experimenter. Outside this window all letters are replaced with erroneous letters, in this case visually similar letters (i.e., the basic shape of the letter is preserved so that round letters are replaced with round letters, for example). The window moves in synchrony with the eyes so that the participant always sees uncorrupted text around the fixation. The reading performance under different window sizes can then be compared with the baseline condition, a condition in which no window is present. When the window size becomes smaller than the letter identity span, reading in the window condition is disrupted in comparison to the baseline condition.

It was shown that the letter identity span extended approx. 5 characters to the right of the fixation for 2nd graders, 7 characters for 4th graders, and 9 characters for 6th graders and adults. Furthermore, it was shown that the letter identity span of faster readers of each age group was larger than that of slower readers. In fact, the letter identity span of faster 4th graders was as large as that of adults on overall, and larger than that of slower adults. Finally, slower 2nd graders were not disrupted by the smallest windows to the same degree as the other reader groups.

The results indicate that the letter identity span develops throughout the elementary school years and that it reaches its maximum around the 6th grade. Adults are still faster readers than 6th graders but this is not caused by a difference in letter identity span. The differences between fast and slow readers of each age group indicate that there are differences in the letter identity span within one class, no matter if children are in the beginning of the elementary school years or in the end. For 2nd graders, it also indicates that the slow but not the fast readers allocate most of their processing resources to the currently fixated word.

Study II

In Study II, the boundary paradigm (Rayner, 1975) was used to examine whether readers extract more parafoveal information (i.e., information outside sharp foveal vision) within than across words. More precisely, it was examined whether readers extract more parafoveal information from a relatively long compound's 2nd constituent when the 1st constituent is fixated than from the same word when it is a spatially separated word in an adjective-noun phrase (kummitustarina 'ghost story' vs. lennokas tarina 'vivid story'). Furthermore, it was examined whether the constituents of a compound word are processed serially or in parallel. For both parafoveal processing issues the developmental trends during the elementary school years were examined. To this end, Finnish 2nd, 4th, and 6th grade children as well as adults were tested.

In the boundary paradigm, a pre-defined target word contains erroneous letters until the participant's eyes cross an invisible boundary set to the left of the target word. During a saccade entering the target word, the word is changed to its correct form, and due to saccadic suppression, a participant does not become aware of the change. If the parafoveal information is extracted, there should be a disruption in comparison to the baseline condition where there is no such change. If processing of foveal and parafoveal information proceeds in parallel, the characteristics of the parafoveal word should influence the reading times of the foveal word, whereas if processing is serial, there should be no disruption in reading the foveal word. In the present study, the first two letters of the parafoveal target words were always preserved whereas the rest of the letters were replaced with visually similar letters.

The results showed that each age group extracted more parafoveal information from a word when it was the 2nd constituent within a compound word than from the same word when it was a noun in an adjective-noun word sequence. Furthermore, it was shown that for each age group there was evidence of parallel constituent processing within compounds, be it that this effect was restricted to cases where the compounds were of high frequency.

Surprisingly, the results imply that there is no difference in the two investigated parafoveal processing issues between 2nd graders and adults. Even 2nd graders extract more information within long compound words than shorter separate words, and, even 2nd graders process constituents of high-frequency compounds in parallel. In these respects, the development of parafoveal processing skills is very swift since after just a little more than a year of reading instruction, children have similar parafoveal processing skills as adult readers (it should be noted that these findings are somewhat difficult to reconcile with the results of Study I, but I will come back to that in the Discussion).

In sum, the results of Study II imply that attention is allocated further to the right and is more parallel in nature when reading words that are spatially and linguistically unified. This indicates that allocation of attention in text processing is flexible in nature, and depends much on the characteristics of the processed text.

Study III

In Study III, we tested whether elementary school children's lexical access of bimorphemic words is mediated by morphemes. Moreover, we tested whether the role of morphemes in lexical access is attenuated as reading proficiency develops. To this end, participants read sentences containing relatively short compound target words that were either concatenated (e.g., *autopeli* 'racing game') or hyphenated (e.g., *ulko-ovi* 'front door'). It was hypothesized that if morphemes are used in lexical access in reading these compound words, signaling the morpheme boundary by means of hyphenation should speed up lexical access. The reasoning behind this hypothesis was that if morphemes are used in lexical access, the morpheme boundary would need to be identified before the individual morphemes could be accessed, and cuing the morpheme boundary explicitly (by hyphen, in this case) would enable readers to bypass the morpheme boundary identification processing stage. In order to investigate the developmental trend in morpheme-mediated access, Finnish 2nd, 4th, and 6th grade children were tested, whereby the 2nd graders were divided into a less proficient and a more proficient group.

It was shown that fast 2nd graders as well as all 4th and 6th graders read concatenated compounds faster than hyphenated compounds. For slow 2nd graders there was an opposite pattern with shorter fixation durations in hyphenated than concatenated compounds. In the interpretation of the results, we made the assumption that a morpheme-based route is more time-consuming than a whole-word route, since it incorporates more processing stages, such as morpheme boundary identification and the activation of individual morphemes. If we assume that whole-word representations are activated via morphemes, there are most probably no semantic integration problems, that is, all the necessary semantics may be activated by such whole-word representations. If, however, the morphemic constituents directly activate their semantics, there will be a need to integrate the semantics of both constituents to come to the conceptual meaning of the whole compound. Either way, given the extra processing stages in morpheme-based access in comparison to whole-word access, one may assume that the former is a slower processing route than the latter. Hence, the results imply that faster 2nd graders as well as older children access concatenated compounds directly via whole-word representations, whereas for hyphenated compounds they have to resort to morpheme-based access. For slower 2nd graders, the results imply that they resort to morpheme-based processing for both types of compound words and that hyphenation facilitates one processing stage of hyphenated compound processing by explicitly signaling the morpheme boundary. Taken together, the results imply that there is a change from morpheme-based processing of concatenated compounds towards processing via whole-word representations as soon as children become more proficient in reading.

Study IV

In Study IV, the role of syllables in lexical access was assessed. In other words, we investigated whether readers use syllables as functional processing units in accessing multisyllabic words. In Experiment 1, Finnish 2nd graders read sentences containing either concatenated (e.g. *kahvi* ‘coffee’) target words or target words where the syllable boundaries were marked with hyphens (e.g., *kah-vi* ‘cof-fee’). It should be noted that Finnish 1st and 2nd graders are used to read words whose syllable boundaries are marked by hyphens, as in 1st grade and to some extent 2nd grade ABC books multisyllabic words are presented with hyphens at these boundaries. We hypothesized that if lexical access of multisyllabic words by 2nd graders is mediated via syllables, they should benefit from an explicit cue signaling the syllable structure. Contrary to our expectations, concatenated words were read faster than hyphenated words, and this difference was enlarged for longer tri- and quadrisyllabic words. However, post-hoc analyses indicated that another cue signaling syllable structure, namely a bigram trough at the syllable boundary (that is, a less frequent bigram around the syllable boundary than the ones preceding and following it; Seidenberg, 1987; Seidenberg & McClelland, 1989), speeded up bisyllabic word processing.

In Experiment 2, we manipulated the presence/absence of a bigram trough at the syllable boundary directly. Also for this experiment, we tested 2nd graders, but these 2nd graders were tested at a later point than the ones in Experiment 1 and hence had been exposed to a longer period of reading instruction and probably gained more reading experience (accordingly, we coined these 2nd graders late 2nd graders and the ones from Experiment 1 early 2nd graders). In Experiment 2, there was a facilitative effect of bigram trough, but – somewhat surprisingly – only for the less proficient (i.e., slower) late 2nd graders. More proficient (i.e., faster) late 2nd graders did not benefit from a bigram trough at the syllable boundary. The finding that more profiecient readers do not benefit from syllable boundary bigram troughs was confirmed in Experiment 3, where we tested Finnish adult readers.

We think that these results indicate that less proficient readers activate syllables before lexical access, but that more proficient readers most likely process short multisyllabic words in a holistic fashion. In addition, they indicate that even though hyphenation may be advantageous in signaling syllable structure, it disrupts attentional and oculomotor processes by virtue of visually dividing the word into smaller units.

Study V

In Study V, we examined the developmental trend in the speed of visual information extraction during reading. To this end, we employed the disappearing text paradigm in which each word disappears after it has been fixated for a pre-designed exposure time (in this study, 60 ms) and does not reappear on the screen until it is refixated after having fixated another word. If 60 ms is not enough to extract information necessary for word processing, it should be manifested in either a slower reading pace or more regressions to disappeared words as such regressions are the only way to get a second visual sample of the word in this paradigm. A combination of these two changes in eye movement behavior is also possible: A slower reading pace and more regressions.

As a previous study showed that young children like adults are not disrupted when words of 6 letters are presented for 60 ms (Blythe et al., 2009), we wanted to investigate whether this is still the case when words are beyond 6 letters long. In other words, we wanted to investigate whether there is a difference in the need of a second visual sample as a function of word length, assuming that the need for a second visual sample is increased for longer words. To this end, we embedded both short 4-letter and long 8-letter target words in sentences and compared how they were read in a disappearing condition in comparison to a normal baseline condition. It is important to notice that the long target words were as frequent as the short ones. (Unlike in English, it is possible to find rather long but still sufficiently frequent words that are known by children.) Finally, to look for developmental trends in the speed of information extraction, we tested 2nd and 4th grade Finnish children as well as adults. We hypothesized that if disappearing text disrupts reading, the effect should be larger for younger children.

It was shown that disappearing text did not disrupt 4th graders' and adults' reading. Even though they made longer fixations on average, there were fewer refixations, and in the end, there was no disruption in overall reading speed caused by the disappearing text condition. The situation was the same for 2nd graders reading short words. However, 2nd graders made more regressions back to long words in the disappearing text condition than in the normal baseline condition.

We think that the results indicate that 4th graders and adults do not need a second visual sample but that they can extract the visual information needed for word processing even for longer 8-letter words within the first 60 ms of fixating the word. On the other hand, 2nd graders are not swift enough to extract all the required visual information for long words within the first 60 ms. That is, it seems that 2nd graders need a second visual sample for long words, and to achieve this, they adapt their eye movement behavior such that they make more regressions to disappeared words.

3. DISCUSSION

In the following, I will discuss the findings of the studies with respect to the three different topics that were examined. Before this, in section 3.1, I will go over some possible shortcomings in these studies. Then, in section 3.2, I will discuss the development of parafoveal processing skills. In section 3.3, I will cover the development in processing multisyllabic and multimorphemic words. In section 3.4, I will discuss the development in the speed of visual information extraction. After these three topics, in section 3.5, I will outline reader profiles for 2nd, 4th, and 6th graders. Then, in section 3.6, I will consider the avenues of future research that are opened by these findings. Finally, in section 3.7, I will present concluding remarks.

3.1 Possible shortcomings of the present studies

There are several possible shortcomings that need to be discussed before moving to the conclusions. The matters concerning eye movement registration and the techniques used in the present studies have already been covered in section 1.4 so they will not be covered here.

In the present dissertation, we have examined the development of reading by testing different groups of children at a same time point. That is, for each study we selected a group of children of the 2nd grade and compared their performance with older children and/or adults. We have taken the results as indicative with respect to the development in reading behavior during the elementary school years. We may be criticized for not testing the same participants at different time points, for this would have reduced within-participant variability and would have yielded a more direct comparison of performance in the 2nd grade in comparison to performance in later grades. Apart from the fact that there were several practical reasons for not choosing a longitudinal design, there are several reasons why I think a comparison between grades at the same time points generates a good picture of the developmental trends in reading performance during the elementary school years.

First of all, Finland is very homogeneous in how reading gets instructed. The Finnish Ministry of Education has set regulations according to what aspects of reading should be taught in every school and at what stage it should take place. Consequently, the materials used in schools are similar in their content, even if not every school uses books by the same authors. However, children in any given school are using exactly the same materials, and for the most part, the 2nd, 4th, and 6th graders used in our studies were from one and the same school. It should be also noted that there are no private schools in Finland (unlike e.g. in the USA), so the quality of the teachers and the constellation of the classrooms are quite similar across schools. For all these reasons, I think that classes within and across schools are quite comparable in terms of the distribution in personal ability and socio-economical background. Therefore I think that the results we found for the 4th graders for instance would not have been notably different if we would have tested the 2nd graders of our studies two years later.[4] In other words, I think that the results of the present dissertation are valid in relation to developmental trends in reading.

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[4] It may also be noted that the basic reading behavior of the 2nd and 4th graders reported in the present studies is similar to that reported by Huestegge, Radach, Corbic and Huestegge (2009) in a longitudinal study. Furthermore, a comparison of the results obtained by the longitudinal design of Huestegge et al. with those obtained

Another issue that has been raised a few times by the reviewers is that we did not include the weakest readers in our studies, that is, we did not include those children that scored way below average in a standard reading comprehension pretests or that responded wrongly on a substantial number of comprehension questions asked during the experiments proper. I have to admit that this might give a slightly more optimistic picture of reading development in Finnish than would have been the case if we would have included these children in our experiments or analyses.

The main reason why we chose to exclude them is that we wanted to test a level of reading at which children comprehend what they read. If reading comprehension is low, one cannot be sure that participants are actually engaged in processes that belong to normal reading, that is, there may be all kind of extraneous processes that do not belong to reading per se. One of the main problems may be that a poor comprehender loses his/her concentration and/or motivation, which may cause that the actual data pattern does not reflect his or her potential ability. Including such participants in the analyses could distort the picture of reading development. Exactly for the same reasons, we made the decision to use 2nd graders and not 1st graders as the youngest participant group. Excluding the weakest readers also reduces the heterogeneity of the subject samples, making the ANOVAs more reliable. At any rate, it seems advisable to always include a reading comprehension test in reading experiments with young children to ensure that the participants are in fact engaged in reading.

Next to the more principled reasons not to include the weakest and/or youngest readers, the decision to exclude them was done on practical grounds as well. Most importantly, the less proficient the reader is, the longer the experiment takes for him/her to finish. Already for the more competent 2nd graders of Study I, the experiment was divided into two sessions. For the less competent 2nd graders and for 1st graders it would have even taken much longer, and we thought it would be unethical to subject our young participants to such long experiments. Alternatively, we could have opted for shorter experiments, but that would have led to unreliable analyses with just a few trials per condition. Finally, with respect to leaving out the 1st graders still, the first study was done with the EyeLink II eye tracker which comes with a helmet designed for adults; using such equipment for 1st graders would have been quite burdensome.

Another issue that may seem quite puzzling is why exactly we chose to test 2nd, 4th, and 6th graders as well as adults. With regard to the 2nd graders, I already noted above that to our minds this was the youngest participant group that could be tested without compromising the length of the experiments. With regard to choosing 6th graders, we wanted to assess the end point of reading development at the elementary school. Also, we wanted to assess how similar 6th graders were to adults in their reading performance. It has been shown that, for instance, 6th graders resemble adults in the size of their global perceptual span (Rayner, 1986), but we wanted to get a more detailed picture as to how 6th graders and adults compare. We hypothesized in our studies that by the 6th grade the development of the phenomena assessed in the present dissertation are at adult level and we wanted to investigate whether this hypothesis was valid. Because the distance between 2nd and 6th grade is quite substantial, we chose to test 4th graders as an in-between group. It would have been the best to test 3rd and 5th graders as well, but due to time constraints this was not

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by a cross-sectional design did not show substantial differences (Ralph Radach, personal communication, February 6th, 2011).

possible. We opted to test 4th graders as an in-between group only, because there is an equal distance between 2nd and 4th as well as 4th and 6th grade.

In the present dissertation, reading speed was used as an index of reading skill within groups and one may ask whether this is an accurate procedure to do so. Below, I try to explain why we chose for this option and why I think reading speed is a good criteria for reading skill. First, we could not make a distinction between less and more proficient readers on the basis of the comprehension questions presented during the experiment as all of our selected participants scored very high on these questions leading to a situation where there were no differences between fast and slow readers in comprehension scores. However, that the difference in reading speed corresponded to a difference in reading skill was confirmed by standardized reading tests (Lindeman, 1998; Nevala & Lyytinen, 2000) that we submitted to the participants before the experiment proper. In these tests fast readers clearly scored above average, whereas slow readers scored below average. The results of our studies also lend support to the rightness of our bifurcation, since fast readers' results were closer to adult-like performance than slow readers' results (e.g., use of whole-word representations, larger letter identity span). So it seems to me that reading speed is a valid way of indexing reading proficiency within a group.[5] However, I realize of course that reading speed and reading skill are continuous variables and it may have been better to treat them as such. Nevertheless, interactions in the ANOVAs with reading speed were typically quite solid and in that sense it seems that there is at least some psychological validity in the notion that reading skill has a significant impact on how words and word sequences are processed. It needs to be noted though that we were not interested in reading speed effects per se but in whether there were interactions involving reading speed. It could have been the case for instance that fast and slow readers would have had a similar letter identity span, only that the slow readers would have extracted letters from within that span more slowly. However, since there was an interaction between reading speed and window size as well as there were interactions between reading speed and other manipulated factors, we could conclude that slow readers read in many ways qualitatively different than fast ones.

Since the children were tested in their own school environment, some noise from the hallways could not be avoided at times. It is possible that this influenced participants' performance to some extent. However, the testing was scheduled to coincidence with the school hours and not with breaks to minimize the possible noise. Furthermore, in case of excessive noise, testing was momentarily stopped. Finally, no participant suffered from noise for more than a few trials, and the majority of trials were read under relatively noise-free circumstances. In other words, I would argue that noise has not been a confounding factor in any of the studies.

Another possible shortcoming in the present dissertation is the number of participants. That is, we did not always manage to get as many participants per participant group as we would have liked to. This was mainly due to time constraints

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[5] It needs to be noted that to some readers may have adjusted their normal reading speed more than others to answer the comprehension questions linked to the experimental task (see e.g., Radach, Huestegge, & Reilly, 2008). This may have led to misclassifications, with some more skillful readers ending up in the less proficient reading group and vice versa. However, given that the interactions with reading proficieny were in the expected direction, we can assume that the bifurcation used in the present studies is a valid (and even a somewhat conservative) estimate of differences between skilled and less skilled readers.

(schools allowing us to disturb them for a certain time period only), availability of participants in each school (due to sickness and due to parents not giving permission for children to participate) and the number of participants that had to be excluded due to low comprehensibility scores and technical problems. As a consequence, we did not have as much statistical power as would have liked to, especially when participant groups were divided in two on the basis of reading speed. However, even with these relatively small groups, we managed to find a substantial number of significant main effects and interactions. Because the lack of participants should manifest in not getting significant effects due to power problems, I think we may consider these effects to be reliable. This leaves alone that there may have been other effects that were not discerned due to the lack of statistical power. Given the limitations described in the beginning of this paragraph, however, there was not much we could do about it.

Finally, in all of the studies, Courier New was used as a font. This font was chosen because it is a non-proportional font meaning that all characters are of equal width. Because of this property it is one of the most preferred font types in eye movement research (e.g., Blythe et al., 2009; Hyönä et al., 2004; Joseph et al., 2009). It is important to have a non-proportional font size, because this ensures that the probability of any given character attracting a fixation is – from a statistical viewpoint – equal. However, it may be the case that this font is less familiar to readers than other fonts used in school books. Because of this Courier New may be harder to read for participants. However, the font type is the same for all participants, and it is likely that when it comes to child participants, they have been exposed to Courier New for more or less the same extent, and thus processing difficulty due to font type should be equal for all of them.

3.2 The development of parafoveal processing skills

Fluent reading requires parafoveal processing skills. During a fixation, a fluent reader typically not only extracts information from letters or words that reside within the foveal area, an area that covers the two inner degrees around a fixation corresponding to approximately 8 characters under normal circumstances. It has been shown time and again that also information from letters and words that reside outside the foveal area or – to put it differently, in the parafoveal area – are extracted during a given fixation. That is, in many boundary studies it was found that when parafoveal word information was altered, subsequent foveal inspection of that word was slowed down (see Hyönä et al., 2004, and Rayner, 1998, for a survey). Recently, Rayner et al. (2006) showed that sentence reading times increased substantially when a parafoveal target word was made to disappear after 60 ms. In other words, it is clear that fluent readers make use of parafoveal information in order to proceed more quickly.

Previous studies assessing parafoveal processing have focused on three issues. Firstly, how far in the parafovea information is extracted, secondly, what is the nature of the information being extracted, and finally, whether processing of foveal and parafoveal information is serial or parallel in nature. In our studies, we aimed to extend on previous findings in several ways. First, in Study I, we investigated the number of letters that could be identified in the parafovea by children. This was done because the development of the letter identity span had not been assessed previously. Furthermore, Study II also manipulated letter identities in the parafovea in order to be able to compare the results of that study to those of Study I. In addition, Study II also investigated whether the amount of information being extracted from the parafovea depends on the spatial and linguistic unification between the foveal and parafoveal word. Finally, Study II aimed to investigate whether processing subsequent words in the context of a compound word is serial or parallel.

The earlier research on parafoveal processing has demonstrated that readers extract useful information for reading up to 14-15 characters to the right of fixation (Rayner, 1998). Furthermore, the amount of parafoveal information extracted from the parafovea depends on certain factors such as reading skill and the nature of information. With regards to the latter, one may say that there are different types of visual-orthographic information that can be extracted from the parafovea, such as word length, letter feature and letter identity information. Rayner (1986) conducted a developmental study in English in which he investigated the word length and letter feature span.

Rayner (1986) demonstrated that the word length span (the area from which word length information is extracted) of English-speaking 2nd and 4th graders is approximately 11 characters to the right of the fixation, whereas for 6th graders and adults it is approx. 14-15 characters. Furthermore, Rayner showed that the letter feature span (the area from which information about letter shapes is extracted) extends to approximately 7 characters to the right of fixation for 2nd graders, whereas it is approx. 11-12 characters for 4th and 6th graders as well as adults. Whereas it is known that adults extract letter feature information from a larger area than letter identity information (e.g., Balota et al., 1985; Pollatsek et al., 1992), this has not been studied for children until the present dissertation. For adults, letter identity information is not extracted further than approximately 10 letters to the right of fixation (McConkie & Rayner, 1975). In Study I, it was shown that the letter identity span (the area from which letter identity information is extracted) develops until the 6th grade. In other words, 2nd graders' letter identity span was approx. 5 characters to the right of fixation, for 4th graders it was approx. 7 characters to the right of fixation, and for 6th graders and adults approx. 9 characters to the right of fixation. This, alongside with Rayner's (1986) findings, demonstrates that all components of the global perceptual span are fully matured by the 6th grade. For some readers the letter identity span is fully matured by the 4th grade already, that is, the letter identity span of faster 4th graders was already as wide as that of adults.

It should be noted that in Study I, we tested the size of the letter identity span in very general terms. That is, the texts that were read by the participants included words of variable length and of variable syllabic and morphological complexity. In addition, sentences with all kinds of syntactic structures were included, which caused that a word from a specific syntactic class could be followed or preceded by a word from the same or any other syntactic class, yielding e.g. adjective-noun, noun-noun, verb-noun, adjective-verb, noun-verb, verb-verb, adjective-adjective, noun-adjective and verb-adjective sequences. In Study II, a much more detailed investigation was done in which we focused on parafoveal processing behavior within compound words and within adjective-noun sequences. The main idea behind this study was to test whether the amount of information extracted from the parafovea was larger within words than across words and also whether the time course of foveal and parafoveal information extraction would be modulated by this manipulation. With respect to the first issue, it was shown that – from the 2nd grade onwards – readers do extract more information from the second constituent noun when fixating the first constituent of a compound word than from exactly the same noun when it is part of an adjective-noun sequence: Change effects were much larger in the former than in the latter case. At the same time, unlike in Study I, we restricted our across-word condition to adjective-noun sequences. Slightly to our surprise, there were solid change effects from 2nd grade onwards for these adjective-noun sequences as well.

If one would believe that parafoveal information extraction is a static, inflexible process that is independent from features such as word length and – as we coined it – syntactic predictability, there would be a discrepancy between the results of Study I and Study II. Most strikingly, in Study I it was shown that 2nd graders' letter identity span is approx. 5 characters to the right of the fixation, whereas the results of Study II indicate that even 2nd graders process parafoveal letter identity information from the end of the second constituent in a compound word as well as the noun in adjective-noun pairs despite the fact that this information is typically much further than 5 characters to the right of the fixation. To us, such a result indicates that parafoveal information extraction is flexible and depends on all kind of lexical and contextual factors.

In our studies, we have worked this idea out in terms of spatial and linguistic unification. That is, we argued that the target compound words in Study II are spatially and linguistically unified and that the adjective and noun in adjective-noun sequences are linguistically unified. Both spatial and linguistic unification seem to affect attentional allocation processes and moreover, it levels out potential differences between readers of different age groups and different reading proficiency skills. It is as if from a very early age onwards readers are aware that when they fixate a word that needs to be integrated with an upcoming word attention should be directed to that upcoming word as soon as possible. As was argued in Study II, this may be to some extent natural in compound words, for which initially the location of the constituent boundary is unclear and attention needs to spread over the whole word to retrieve the word as a whole or to parse out the first constituent. However, the fact that attention is also allocated to the noun while fixating the adjective in adjective-noun sequences indicates that children quickly learn that under some circumstances it may be beneficial to 'open up' their attentional span. Taken together, results of studies I and II indicate that – globally speaking – the more proficient a reader, the larger the area from which s/he can extract detailed information such as letter identities, but it also seems that at times less proficient readers can – driven by certain lexical and contextual factors – upgrade their attentional system to an adult level. The following section on serial vs. parallel processing underlines this assertion.

In the existing literature, there is a vivid debate about the time course of parafoveal information extraction with one group of scholars claiming that it is extracted after foveal information extraction and another group of scholars claiming that it may be simultaneously extracted. More precisely, parallel processing models of reading (e.g., SWIFT; Engbert et al., 2005) posit that several words may be processed simultaneously and that, because of this, characteristics of parafoveal words may influence processing times of foveal words (parafoveal-on-foveal effect, PoF; Kennedy, 2000). On the other hand, serial processing models (e.g., E-Z Reader; Pollatsek et al., 2006; Reichle et al., 2003) posit that a fixated word needs to be identified before attention can be allocated to the next word, so these types of models do not predict PoF effects. So far, the evidence on PoF effects is ambiguous. That is, there are studies in which they are found (e.g., Kennedy, 2000; Kennedy et al., 2002; Kliegl et al., 2007; White, 2008) and studies who fail to find PoF effects (e.g., Altarriba et al., 2001; Hyönä et al., 2004; Pollatsek et al., 1992). Proponents of serial accounts claim that studies that have reported PoF effects have often used paradigms that mimic reading but are not (see Rayner, White, Kambe, Miller, & Liversedge, 2003). In case PoF effects emerge in real reading these proponents claim that they can be accounted for by mislocated fixations. According to the mislocated fixations account (Drieghe et al., 2008), possible PoF effects are due to fixations that were aimed at the next word but due to oculomotor programming error landed on the previous word, even though attention is already directed to the next word.

All of the studies reported above have tried to find PoF effects across words. However, recently a number of boundary studies have tried to find PoF effects within biconstituent compound words (e.g., Hyönä et al., 2004; Juhasz et al., 2009; Pollatsek & Hyönä, 2005; White et al., 2008). If real PoF effects are anywhere to be observed, one may argue that biconstituent compounds are the most likely place to find them. However, even though there were some numerical change effects in Gaze Duration of the first constituent in these studies, there has been no solid evidence for PoF effects.

In contrast, Study II of this dissertation was the first to show a solid PoF effect within compounds, and, perhaps surprisingly, this effect was found for all age groups. In other words, it was shown that all age groups extracted letter identity information from the end of the second constituent while fixating the first constituent of a compound word. It should be noted, however, that this evidence for parallel constituent processing was restricted to high-frequency compounds, which were of higher frequency than compound words in earlier studies examining parafoveal constituent processing (e.g., Hyönä et al., 2004; Pollatsek & Hyönä, 2005; White et al., 2008). The finding, that the constituents of high-frequency compounds may be processed simultaneously whereas for low-frequency compounds attention is swiftly directed to one constituent, suggests that – even within compound words – there is no principled distinction between serial and parallel processing. Also here, lexical factors such as word frequency play a large role, and if compound processing as such would be incorporated in eye movement models of reading, this notion should be taken into consideration as well. Our results at least indicate that the size of the attentional span may fluctuate as a function of word characteristics, and the precense of PoF effects suggests that attention may spread over more than one word under optimal circumstances. In other words, one may say that for compound processing a strictly sequential processing view is not likely and instead, there is at least some parallel component involved in constituent word processing.

At any rate, it is amazing that we found PoF effects for younger children, especially the 2nd graders, even more so because the first 2 letters of the second constituent were preserved and of the remaining letters letter feature information was preserved. This indicates that even 2nd graders are processing relatively detailed orthographic information from the parafoveal area. We think that this finding is connected to the idea that once readers encounter a long word, they simultaneously try to match the word with a whole-word representation as well as that they try to locate possible morpheme boundaries in order to split the word up in more digestible pieces. During these initial stages, they already extract some information from the parafoveal part of the word and this in turn will lead to the PoF effects. The fact that PoF effects are restricted to high-frequency compounds only suggests that children (and adults alike) sustain their initial attention for a longer time over the whole word when the chances to identify that word via a whole-word representation are higher. Since, in Study II, two letters of the parafoveal constituent were always preserved, it seems that initial attention stretches to the end part of the compound word, at least in Finnish.

One may wonder to what extent our findings will be replicable in English, for example. It is clear that the findings for the global letter identity span in Finnish (Study I) tie in well with the results of Rayner (1986) in English on other components of the global perceptual span (Rayner, 1986). However, it may be harder to find large change effects within compounds and adjective-noun sequences for English children as well as it may be difficult to find PoF effects for young English children. It may be the case that the properties of Finnish are such that it encourages children to engage in deeper and/or more extensive parafoveal processing than in English. For one thing, in comparison to English, Finnish words are relatively long. This is mainly due to extreme morphological productivity of Finnish (for details, see section 1.3). In other words, already from young age Finnish children are used to the fact that there is important semantic and syntactic information in the latter part of the word and it may well be that these properties of the language will encourage them to allocate their attention more swiftly and intensively to the latter part of words than children of other language. One could speculate that Finnish children get more practice in extending their attentional span and develop a system that is more flexible than for instance English children. It may be the case that in languages more similar to Finnish than English one may find similar effects with regard to parafoveal processing.

3.3 The development in multisyllabic and multimorphemic word processing

As I argued in the introduction, it has been shown that children use both syllables (e.g., González & Valle, 2000; Maïonchi-Pino et al., 2009) and morphemes in lexical access (Bertram et al., 2000; Colé et al., 2005). These findings are in line with developmental theories of reading (e.g., Ehri, 1987, 1989) which posit that as readers become more proficient they start to use sublexical units beyond the letter to obtain lexical access. In Study III and IV this was confirmed as we found evidence for both the syllable (Study IV) and the morpheme (Study III) to mediate lexical access. Both studies were remarkably similar in showing effects for less proficient 2nd graders only, but not for more proficient 2nd graders or older children or adults anymore. We assumed that with increasing reading proficiency printed words are directly mapped onto whole-word representations without a mediating role of larger-sized sublexical units such as syllables and morphemes. I would like to add that we do not want to claim that the sublexical route is not attempted, in fact we believe that the processing system tries to make use of all possible cues that may lead to fast lexical access, but in case of the more proficient readers in our studies it seems that the sublexical route does not have a functional contribution to lexical access. That is, it seems that the whole-word processing route is faster.

Turning to the specific studies in more detail, in Study III, we got evidence for the above-stated account, where we showed that fast 2nd graders as well as all 4th and 6th graders processed concatenated compounds faster than hyphenated compounds. This finding, coupled with the finding that slow 2nd graders had shorter fixation durations in hyphenated than concatenated compounds, was taken as evidence that children start to use whole-word access units as their proficiency grows. In Study IV, it was shown that less proficient 2nd graders do make use of syllable information as manifested in an implicit syllable boundary cue facilitating multisyllabic word processing. However, for more proficient 2nd graders a change toward more holistic processing was shown, since they were not advantaged by such a cue anymore. Also adults in Study IV did not benefit from syllable structure information. These findings are further evidence that Finnish children become relatively proficient readers rapidly (e.g., Poskiparta et al., 1999; Seymour et al., 2003) and demonstrate that – at least for the relatively high-frequency words we used in our studies – both syllables and morphemes are used in lexical access in the early phases of elementary school, but that already during the 2nd grade some children learn to access words via holistic representations..

As noted before, we do not argue that smaller units are not in use for proficient readers at all. Word processing is a complex process, and – as I noted in the introduction – there are many factors that affect word processing speed. However, one could say that in the early phases of reading children do not have all the ‘tools’ available to process words as quickly as possible, or, to put it differently, that proficient readers have in fact more tools to use in word processing, for instance stable whole-word representations allowing for rapid lexical access. We – and with us many other researchers – have assumed that the development of such representations depend very much on the frequency of exposure, the more frequent a word is, the more stable the whole-word representation and the more quickly it can be retrieved. Naturally, it also depends on the frequency of sublexical units. Perhaps smooth reading can be defined as making optimal use of the sublexical and lexical properties of a word, to find the delicate balance between different units within a word to retrieve the word’s meaning as quickly as possible. It is – of course also on a sublexical level – more likely to make use of units that are of high frequency.

In this respect, it may be good to note that in Finnish, there is no public database for syllable frequencies with regard to individual syllables so the syllable frequency could not be controlled for, even though the words were matched on bigram frequency, for example. It may the case that for low-frequency syllables the picture would be different. With regard to morpheme-level processing, it may be the case that whole-word representations are more effective in uninflected compound words, such as the ones used in Study III. Because Finnish has an enormous number of possible inflectional forms for virtually every word, there possibly cannot be whole-word representations for every form. Therefore, it is very likely that Finnish readers resort to morpheme-based processing during lexical access to a large extent, and the finding that concatenated compound words can be accessed via their whole-word representations is just valid for compounds that are not further inflected.

In support of the interplay between sublexical and lexical processes, Colé, Segui, and Taft (1997) showed that lexical decision latencies for derived French words are a function of word frequency as long as the constituent morphemes are of lower frequency and a function of morphemic frequency when word frequency is lower than constituent morpheme frequencies. Similarly, Kuperman, Bertram, and Baayen (2008, 2009) showed that properties of constituent morphemes less prominently influence multimorphemic processing with increasing word frequency. As mentioned in the introduction, for children also Bertram et al. (2000) and Burani et al. (2008) found evidence for a similar interplay between frequency and processing route.

Naturally, age as such also plays a role in this process: The more experienced readers get, the more frequent words become in readers’ lexicons and the more readily whole-word representations can be used in lexical access. On the other hand, it is also likely that more proficient readers have better developed skills in processes related to decomposition such as locating boundaries within words. What we would argue for is a flexible processing system in which all kind of factors influence how a word is eventually retrieved from the mental lexicon. Naturally, as mentioned above, this flexibility should be captured in all morphological processing models. However, the results of Study III and IV show that with increasing proficiency it is more likely that familiar words are processed in a holistic fashion. Nevertheless, it needs to be noted that holistic processing of compounds may be restricted to short compounds in which all the sublexical and lexical information can be extracted at once, whereas even for adults in long compounds the first constituent may have a visual acuity benefit over the second constituent and thus the whole word may not be processed at once (Bertram & Hyönä, 2003).

As noted above, the development of larger access units goes against the spirit of the psycholinguistic grain size theory (Ziegler & Goswami, 2005) which proclaims that for shallow languages like Finnish there is no need for the development of such units. In principle, one could indeed assume that by virtue of the perfect grapheme-phoneme correspondence in Finnish access may be mediated via the letter-level. An advocate of the grain size theory may even point out that the lack of syllable and morpheme effects for more proficient readers is in line with their predictions. I certainly would have agreed with this, if the lack of such effects would not have been preceded by solid syllable and morpheme effects for the less proficient readers. To my mind, these effects underline that also in Finnish the path to fluent reading is larded with the development of larger-sized orthographic units and this is more in line with several theories of reading development (e.g., Ehri, 1987; 1989; Frith, 1985) than the psycholinguistic grain size theory.

3.4 The development of the speed of visual information extraction

How much time is needed to extract so much the visual information from a word that it can be processed fluently? This is a question that was asked by a group of Anglo-American researchers a few years ago and in order to answer this question they designed the disappearing text paradigm, a paradigm in which words disappeared during the first fixation after an experimenter-defined interval (e.g., Blythe et al., 2009; Liversedge et al., 2004; Rayner, Liversedge, et al., 2003; Rayner et al., 2006). They found that 40-57 ms is enough to process relatively short words. Amazingly, this is true even for 2nd grade English-speaking children. More specifically, Blythe et al. (2009) demonstrated that also 7-year-old children only require 40-60 ms to extract sufficient visual information from a 6-letter word so that linguistic processing can be initiated normally. In other words, 60 ms is enough for retinal stimulation to produce excitation in the visual cortex so that there is enough visual information for linguistic processing to start (Rayner, Liversedge et al., 2003). Fluent processing of disappearing words was supported by the fact that children did neither read 6-letter words slower nor did they require a second visual sample more often (regressions back to target words) under the disappearing condition than under the normal condition (Blythe et al., 2009). However, one thing they did not study was how word length affects the speed of visual information extraction. Previously, it has been shown that longer words are slower to process than shorter words (Rayner, 1998). Furthermore, McConkie et al. (1991) showed that for younger readers the refixation probability grows steeper as a function of word length than for adult readers. Given these findings together, we speculated that in case of longer words more time is needed to extract all the necessary visual information from a word.

In Study V, we showed that also for Finnish 2nd graders, 4th graders and adults an exposure time of 60 ms is enough to extract all the necessary visual information of short 4-letter words for processing to proceed smoothly. That is, the words of 4 letters were read equally fast and were not regressed to more often in the disappearing text condition in comparison to the normal text condition.

A similar pattern was found for 8-letter long words for the 4th graders and adults, but it was also shown that in case of the 2nd graders there was a greater need for regressions to words of this length under the disappearing text condition than under the normal text condition. This implies that they were not able to extract all the visual information that was needed to fully understand the disappearing word and that a second sample was often needed to get further visual information on the disappearing word.

How could this be explained? It should be noted that the letter identity span of 2nd graders as such should be big enough to identify – at least most of the time – all 8 letters of 8-letter words fully, since initial fixations were typically around the third letter of the word. However, it seems that 60 ms is not enough for 2nd graders to get all of the required information of 8-letter words into the visual system and it just implies that the system is still under development. In the future, it would be good to test longer exposure times to assess how much exposure time is needed to extract the necessary visual information of words that are relatively long.

The findings of Study V, coupled with earlier disappearing text studies, also seem to indicate that most of the refixations in normal reading are redundant, at least for proficient readers reading words up to 8 letters, since there was no overall disruption in reading the disappearing text, that is, overall reading times were the same (or sometimes even a bit faster) and the number of regressions was also similar in the normal and disappearing text condition. Even though fixations were longer in the latter condition, it was compensated by making fewer fixations.

All in all, it seems that visual information is extracted very swiftly from a written word, which may be explained from an evolutionary viewpoint, namely the fact that to survive in nature people have needed to detect information very quickly. It is notable that proficient readers relatively effortlessly employ the brain's cognitive possibilities in the task of reading, and furthermore, they are relatively quick in reaching a certain level of proficiency where reading is automatized. The current study is in line with the evidence gathered from other studies and leads to the conclusion that the visual system related to reading is in full use at a relatively early stage.

3.5 Reader profiles for elementary school

The current dissertation has investigated the development of reading during elementary school years in several distinct but related areas. What is perhaps most notable is that in all these areas children make very quick progress. This will be reflected in the reader profiles of 2nd, 4th and 6th grade children as sketched below.

2nd grade

It seems that for 2nd graders one may distinguish between more proficient and less proficient readers, but we found that even the latter group shows some signs of adult-like performance in that they are for instance capable of processing information from the next, spatially separated parafoveal word in adjective-noun sequences. Furthermore, they process a lot of information from the end of a long compound word when they fixate its beginning as well as they seem to be able to process information from two constituents in a compound in parallel if they are of high frequency. This shows that initially even less proficient 2nd graders are able to allocate attention over a larger area than currently fixated words, even though they clearly make use of smaller units (i.e., syllables and morphemes) during word identification. It is amazing that the more proficient 2nd graders already resemble adults in many respects. As the less proficient readers, they engage in preprocessing the nouns in adjective-noun sequences as well as they engage in parallel constituent processing of high-frequency compounds. In addition to this, they almost reached adult level in their letter identity span (just 2 characters less than that of adults) and they addressed multimorphemic and multisyllabic words by their whole-word representations, just as older children and adults did.

4th grade

When it comes to 4th graders, reading performance was even more similar to adults. The only deviant result was that less proficient 4th graders’ letter identity span was as wide as that of 2nd graders in general. However, the letter identity span for more proficient 4th graders was found to be as wide as that of adults in general, and in fact wider than that of slow adult readers. Moreover, 4th graders performed (at least) equally well on disappearing words as adults no matter whether words were long or short. Having said this, I would like to note that numerical tendencies for the 4th graders were not always in line with the statistical analyses. That is, in our studies we used quite complex designs with a lot of variation in reading skill, especially between classes. In such designs it is not easy to find interactions between a given variable and age group. For instance, the analyses of Study II suggested that 4th graders can process information from both constituents in a high-frequency compound in parallel, but this interpretation was due to a main change effect in first constituent gaze duration in combination with a lack of interaction between change and age group. In fact, numerically, there was no evidence for parallel processing within high-frequency compounds for 4th graders and also when analyzing the 4th grade separately the evidence for this effect was far from significant. On the basis of these separate analyses, we could have concluded that 4th graders do not need information from the whole word to be able to focus on the beginning part of the word. In combination with the findings of Study III in which we found that 4th graders nevertheless prefer to process concatenated compounds via whole-word representations instead of resorting to morpheme-based processing, we could have argued that 4th graders initially focus on a smaller area than 2nd graders, but that they can widen their attentional span swiftly if they notice that the word in question is easier to process via its whole-word representation.

In addition, 4th graders were in fact faster in the disappearing text condition than in the normal condition as indexed by total sentence reading time. This numerical trend was also present for adults, but not nearly as big as for 4th graders (78 ms vs. 240 ms, respectively). However, again due to the lack of an interaction between group and text presentation format, we did not make any further speculations on this finding. One such speculation could have been that 4th graders are already more comfortable with disappearing text than with normal text as they belong to a generation of highly proficient gamers that are used to information being changed quickly. However, as the deviant findings for 4th graders were not solid, we refrained from such speculations, although the results do warrant further and more detailed examination of 4th graders’ reading behavior in comparison to younger and older age groups.

6th grade

First of all, it should be noted that 6th graders were not tested in every study of the present dissertation. However, on the basis of the studies in which they were included we can say that Finnish 6th graders have fully matured with regard to their perceptual span and parafoveal processing skills. They are able to preprocess information from the latter part of nouns in adjective-noun sequences, and – as the other age groups – they even preprocess more information from the same nouns when these nouns function as a second constituent in noun-noun compounds. Within high-frequency compound words, they can also extract foveal and parafoveal letter identity information in parallel. All in all, 6th graders are quite proficient readers, but it needs to be noted that in all our studies word processing times of adults were still shorter than those of 6th graders (or any other child group). To my mind this can be described as a frequency effect in disguise, that is, the longer exposure to different texts have made words and probably also word combinations and several syntactic constructions simply more frequent for adults and therefore more easily accessible in the (extended) mental lexicon.

3.6 Future avenues of research

Eye movement recording has been used extensively to investigate reading behavior of adult readers (see Rayner, 1998, for a survey). As I noted at several places in this dissertation, eye movement research on children's reading behavior has been extremely scarce. This is unfortunate, since eye movement recording can offer a great tool to examine on-line processing of reading accurately. Naturally, there are methods for assessing reading off-line (e.g., measuring the reading speed for the whole text) but with these methods one cannot tap into the time-course of word processing as accurately as eye movements. Furthermore, other methods assessing on-line processing of reading, such as self-paced reading for instance, do not provide such detailed information about the course of word processing. This is not to say that one cannot assess aspects of reading by other means than eye movement registration. However, with the help of eye movement registration even the smallest details of reading behavior can be captured, and it can reveal the developmental trajectories in a powerful way. With the current fast development of eye tracking devices, high acuity tracking allowing free head movement without any helmets or chinrests is becoming a real possibility, meaning that even the youngest children can be tested with this methodology. This dissertation and other recent studies from a research group in England (e.g., Blythe et al., 2009; Joseph et al., 2009) give perhaps instigation to further unclose the study of reading development by means of eye movement registration. In the following, I will go over some ideas – both broader and more detailed – as to what can be examined with eye tracking methodology.

Children read orally to a large extent at least in Finnish elementary schools as part of reading instruction, whereas adults most often engage in silent reading. It is important to realize that proficient silent reading is the goal that reading instruction aims at. Nevertheless, during elementary school years poor oral reading performance is often taken as an indication that a child has difficulties with reading. However, it is possible that for some young readers oral reading itself is hard, even though their technical reading performance (i.e., visual information extraction and lexical access) is not hampered. More precisely, it is known from earlier studies that the eyes are typically ahead of the voice in reading aloud (a phenomenon coined the eye-voice span, see e.g., Levin & Buckler-Addis, 1979) and it may well be that a child who has problems with reading aloud has problems with the optimal coordination of eyes and voice instead of having problems that come with silent reading. While tracking eye movements, one could compare readers who seemingly perform similar in silent reading, but not in reading aloud and assess whether there are systematic differences in the eye-voice span between the two reader groups.

Another area where eye tracking has been used is sentence processing as well as or in combination with reading strategies, for both adults (e.g., Hyönä, Lorch, & Kaakinen, 2002) and children (e.g., Kim, Knox, & Brown, 2007; Trauzettel-Klosinski, Koitzsch, Dürrwächter, Sokolov, Reinhard, & Klosinski, in press). However, further research on these strategies and their developmental trajectories is needed. Because eye movement registration can be used to tap into different strategies readers use during sentence processing, it may also be used to detect children with reading difficulties. This is not to say that children with reading difficulties cannot be screened out by other means, such as standardized reading tests (e.g., Lindeman, 1998; Nevala & Lyytinen, 2000), but thanks to its accuracy, eye movement registration may be a tool with which more fine-grained details of reading difficulties can be examined. I believe that eye movements may even help in the diagnosis of dyslexia. That is, it may be for instance and indication of dyslexia, when the global perceptual span (or some of its components) clearly deviates from average. Because the present dissertation does not tap into whether the wider perceptual span is a precondition of good reading proficiency or just a consequence of growing proficiency, one could design an intervention study for children with reading difficulties to study this issue in more detail (e.g., does the perceptual span get substantially wider for those children who benefit from an intervention?). At any rate, even though dyslexia has been studied by eye movements to some extent already, more insight into dyslexia can be gained still by conducting more advanced experiments with dyslexic readers using similar paradigms as the ones used in the present dissertation.

Finally, with regard to more skilled reading, eye movement tracking could be used for preparing optimal text books for children so that the books themselves would facilitate reading to the fullest extent. For example, one could test whether the amount of words per line, the font or the font size affects developing children's reading (e.g., Bernard, Chaparro, Mills, & Halcomb, 2002). An example of how eye movement research could tap into the issue of text presentation is our Study IV, in which it was shown that hyphenation disrupts 2nd graders' reading to a large extent, even though hyphenation is preserved in 2nd grade ABC books up to the end in long and novel words. However, it may be the case that hyphenation aids in other aspects such as spelling (M.-K. Lerkkanen, personal communication, February 23, 2009). On the other hand, most 2nd grade children seem to be using syllable information in lexical access. Therefore, it would be important to test whether syllable structure could be signaled by other means such as bolding, which would not be as disruptive to reading process. As we have argued, since hyphenation divides the word into smaller units, oculomotor and attentional processes may be severely disrupted, whereas other means of signaling the syllable structure might not do this to the same extent, as shown in Study IV with regard to bigram troughs. Therefore, it would be important to assess whether there is a way of explicitly signaling the syllable structure without disrupting other processes related to reading.

3.7 Concluding remarks

Reading is a very complex task. However, proficient readers seem to perform it with very little effort. Even long sentences can be read in just a few seconds. However, what we do as readers during these seconds is quite remarkable. We need to match the visual information with word representations in our mind, retrieve the meaning of separate words, assign a syntactic role to all of them, and integrate this information into a sentence-level representation to understand the meaning of the whole sentence. Furthermore, this representation is kept active in working memory so that we can integrate this information with the upcoming sentence and so on. Yet, for many people these huge cognitive tasks seem to proceed quite effortlessly. Moreover, it seems that relatively young children acquire all the skills needed for fluent reading at a fast rate.

As I have shown, the work of the eyes is a major factor in the reading process, and it is therefore important to know how it contributes to make something seemingly difficult in many cases apparently easy. It is clear that children rapidly develop their reading skills during the elementary school years, and this development is also reflected in the development of eye movement behavior during reading. It is intriguing to note that young children can swiftly extract visual information, can adapt their attentional focus to textual properties, quickly develop larger-sized access units, have already an impressively large perceptual span, and can – under certain circumstances – even process information of subsequent words in parallel. It is even more fascinating to realize that all these skills are at an adult level at the end of the elementary school years.

REFERENCES

Abrams, S.G., & Zuber, B.L. (1972). Some temporal characteristics of information processing during reading. *Reading Research Quarterly, 12*, 41-51.

Alegre, M., & Gordon, P. (1999). Frequency effects and the representational status of regular inflections. *Journal of Memory and Language, 40*, 41-61.

Altarriba, J., Kambe, G., Pollatsek, A. & Rayner, K. (2001). Semantic codes are not used in integrating information across eye fixations in reading: Evidence from fluent Spanish English bilinguals. *Perception and Psychophysics, 63*, 875–890.

Anglin, J.M. (1993). Vocabulary development: A morphological analysis. *Monographs of the Society for Research in Child Development*, 58, 1-165.

Ashby, J., & Martin, A.E. (2008). Prosodic phonological representations early in visual word recognition. *Journal of Experimental Psychology. Human Perception And Performance, 34*, 224-236.

Balota, D.A., & Chumbley, J.I. (1984). Are lexical decision a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology. Human Perception And Performance, 10,* 340-357.

Balota, D.A., Pollatsek, A. & Rayner, K. (1985). The interaction of contextual constraints and parafoveal visual information in reading. *Cognitive Psychology, 17*, 364–390.

Balota, D.A., Yap, M.J., & Cortese, M.J. (2006). Visual word recognition: The journey from features to meaning (a travel update). In M. Traxler & M. Gernsbacher (Eds.), *Handbook of Psycholinguistics*. (pp. 285-374). London: Academic Press.

Becker, C.A. (1979). Semantic context and word frequency effects in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 5*, 252-259.

Bernard, M.L., Chaparro, B.S., Mills, M.M., & Halcomb, C.G. (2002). Examining children’s reading performance and preference for different computer-displayed text. *Behaviour & Information Technology, 21,* 87-96.

Bertram, R., & Hyönä, J. (2003). The length of a complex word modifies the role of morphological structure: Evidence from eye movements when reading short and long Finnish compounds. *Journal of Memory and Language,* 48, 615-634.

Bertram, R., Laine, M., & Virkkala, M.M. (2000). The role of derivational morphology in vocabulary acquisition: Get by with a little help from my morpheme friends. *Scandinavian Journal of Psychology*, 41, 287-296.

Blythe, H.I., Liversedge, S.P., Joseph, H.S.S.L., White S.J., & Rayner, K. (2009).Visual information capture during fixations in reading for children and adults. *Vision Research, 49,* 1583-1591.

Brand, M., Rey, A., & Peereman, R. (2003). Where is the syllable priming effect in visual word recognition? *Journal of Memory and Language, 48*, 435-443.

Burani, C., Marcolini, S., De Luca, M., & Zoccolotti, P. (2008). Morpheme-based reading aloud: Evidence from dyslexic and skilled Italian readers. *Cognition*, 108, 243-262.

Burani, C., Marcolini, S., & Stella, G. (2002). How early does morpholexical reading develop in readers of a shallow orthography? *Brain and Language, 81*, 568-586.

Buswell, G.T. (1922). *Fundamental reading habits: A study of their development.* Chicago: University of Chicago Press.

Carlisle, J.F. (2000). Awareness of the structure and meaning of morphologically complex words: Impact on reading. *Reading and Writing*, 12, 169-190.

Carlisle, J.F., & Stone, C.A. (2005). Exploring the role of morphemes in word reading. *Reading Research Quarterly, 40*, 428-449.

Carpenter, P.A., & Just, M.A. (1983). What your eyes do while your mind is reading. In K. Rayner (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 275-307). New York: Academic Press.

Cipiliewski, J., & Stanovich, K.E. (1992). Predicting growth in reading ability from children's exposure to print. *Journal of Experimental Child Psychology, 54*, 74-89.

Colé, P., Magnan, A., & Grainger, J. (1999). Syllable-sized units in visual word recognition: Evidence from skilled and beginning readers of French. *Applied Psycholinguistics*, 20, 507–532.

Colé, P., Royer, C., Hilton, H., Marec N., & Gombert, J.-E. (2005). Morphology in reading acquisition and in dyslexia. In J.-P. Jaffré, J.-C. Pellat, & M. Fayol (Eds.), *The semiography of writing, Tome 2*. Dordrecht, The Netherlands: Kluwer.

Colé, P., Segui, J., & Taft, M. (1997). Words and morphemes as units for lexical access. *Journal of Memory and Language, 37*, 312-330.

Coltheart, V., Laxon, V.J., Keating, C. (1988). Effects of word imageability and age of acquisition on children's reading. *British Journal of Psychology, 79*, 1-12.

Conrad, M., Carreiras, M., Tamm S., & Jacobs A.M. (2009). Syllables and bigrams: Orthographic redundancy and syllabic units affect visual word recognition at different processing levels. *Journal of Experimental Psychology: Human Perception and Performance*, 35, 461-479.

Drieghe, D. (2008). Foveal processing and word skipping during reading. *Psychonomic Bulletin & Review*, 15, 856-860.

Drieghe, D., Rayner, K., & Pollatsek, A. (2008). Mislocated fixations can account for parafoveal-on-foveal effects in eye movements during reading. *Quarterly Journal of Experimental Psychology*, 61, 1239-1249.

Ehri, L.C. (1987). Learning to read and spell words. *Journal of Reading Behavior*, 19, 5-31.

Ehri, L.C. (1989). The development of spelling knowledge and its role in reading acquisition and reading disability. *Journal of Reading Disabilities*, 22, 356-365.

Elbro, C., & Arnbak, E. (1996). The role of morpheme recognition and morphological awareness in dyslexia. *Annals of Dyslexia, 46*, 209-240.

Engbert, R., Nuthmann, A., Richter, E., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112*, 777-813.

Feldman, L.B., Rueckl, J., DiLiberto, K., Pastizzo, M., & Vellutino, F.R. (2002). Morphological analysis by child readers as revealed by the fragment completion task. *Psychonomic Bulletin & Review*, 9, 529-535.

Ferrand, L., & New, B. (2003). Syllabic length effects in visual word recognition and naming. *Acta Psychologica, 113*, 167-183.

Ferrand, L., Segui, J., & Humphreys, G.W. (1997). The syllable's role in word naming. *Memory & Cognition, 25*, 458-470.

Ferreira, F., & Henderson, J.M. (1990). Use of verb information in syntactic parsing: Evidence from eye movements and word-by-word self-paced reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 555-568.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. Patterson, J. Marshall & M. Coltheart (Eds.), *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading.* (pp. 301–330). London: Erlbaum.

Frost, R., Deutsch, A., & Forster, K. I. (2000). Decomposing morphologically complex words in a nonlinear morphology. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26, 751-765.

Gerhand, S., & Barry C. (1998). Word frequency effects in oral reading are not merely age-of-acquisition effects in disguise. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 267-283.

Giraudo, H., & Grainger, J. (2001). Priming complex words: Evidence for supralexical representation of morphology. *Psychonomic Bulletin & Review,* 8, 127-131.

González, J., & Valle, I. (2000). Word identification and reading disorders in the Spanish language, *Journal of Learning Disabilities*, 33, 44–60.

Goswami, U., & Bryant, P.E. (1990). *Phonological skills and learning to read.* Hove, UK: Psychology Press.

Goswami, U., Gombert, J., & De Barrera, F. (1998). Children's orthographic representations and linguistic transparency: Nonsense word reading in English, French, and Spanish. *Applied Psycholinguistics, 19,* 19-52.

Henderson, J.M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 417-429.

Huestegge, L., Radach, R., Corbic, D., & Huestegge, S.M. (2009). Oculomotor and linguistic determinants of reading development: A longitudinal study. *Vision Research, 49*, 2948-2959.

Huey, E.B. (1908). *The psychology and pedagogy of reading.* New York: Macmillan.

Hyönä, J., Bertram, R. & Pollatsek, A. (2004). Are long compound words identified serially via their constituents? Evidence from an eye-movement contingent display change study. *Memory and Cognition, 32,* 523–532.

Hyönä, J., Lorch, R.F., & Kaakinen, J.K. (2002). Individual differences in reading to summarize expository text: Evidence from eye fixation patterns. *Journal of Educational Psychology, 94*, 44-55.

Hyönä, J. & Olson, R.K. (1995). Eye fixation patterns among dyslexic and normal readers: Effects of word length and word frequency. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 1430 - 1440.

Hyönä, J., & Pollatsek, A. (1998). Reading Finnish compound words: Eye fixations are affected by component morphemes. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1612-1627.

Inhoff, A.W., Radach, R., Starr, M., & Greenberg, S. (2000). Allocation of visuo-spatial attention and saccade programming during reading. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.). *Reading as a perceptual process,* pp. 221-246. Oxford: Elsevier.

Inhoff, A.W., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics, 40*, 431-439.

Jacobson, J.Z., & Dodwell, P.C. (1979). Saccadic eye movements during reading. *Brain and Language, 8,* 303-314.

James, C. T. (1975). The role of semantic information in lexical decisions. *Journal of Experimental Psychology: Human Perception and Performance, 1,* 130-136.

Jared, D., & Seidenberg, M.S. (1990). Naming multisyllabic words. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 92-105.

Joseph, H.S.S.L., Liversedge, S.P., Blythe, H.I., White, S.J., Gathercole, S.E., & Rayner, K. (2008). Children's and adults' processing of anomaly and implausability during reading: Evidence from eye movements. *Quarterly Journal of Experimental Psychology, 61*, 708-723.

Joseph, H.S.S.L., Liversedge, S.P., Blythe, H.I., White, S.J., & Rayner, K. (2009). Word length and landing position effects during reading in children and adults. *Vision Research, 49*, 2078-2086.

Juhasz, B.J., Pollatsek, A., Hyönä, J., Drieghe, D., & Rayner, K. (2009). Parafoveal Processing Within and Between Words. *Quarterly Journal of Experimental Psychology,* 62, 1356-1376.

Just, M.A., Carpenter, P.A., & Woolley, J.D. (1982). Paradigms and processes in reading comprehension. *Journal of Experimental Psychology: General, 111*, 228-238.

Karlsson, F., & Koskenniemi, K. (1985). A process model of morphology and lexicon. *Folia Linguistica, 29*, 207-231.

Kennedy, A. (2000). Parafoveal processing in word recognition. *Quarterly Journal of Experimental Psychology, 53A*, 429–455.

Kennedy, A., Pynte, J., & Ducrot, S. (2002). Parafoveal-on-foveal interactions in word recognition. *Quarterly Journal of Experimental Psychology, 55A*, 1307–1337.

Kim, K., Knox, M., & Brown, J. (2007). Eye movement and strategic reading. In Y. Goodman, & P. Martens (Eds.). *Critical issues in early literacy: Research and Pedagogy*. (pp. 48-57). Mahwah, NJ: Lawrence Erlbaum Associates.

Kliegl, R. Nuthmann, A., & Engbert, R. (2006). Tracking the mind during reading: The influence of past, present, and future words on fixation durations. *Journal of Experimental Psychology: General, 135*, 12-35.

Kliegl, R., Risse, S., & Laubrock, J. (2007). Preview benefit and parafoveal-on-foveal effects from word n+2. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1250-1255.

Kuperman, V., Bertram, R., & Baayen, R.H. (2008). Morphological dynamics in compound processing. *Language and Cognitive Processes, 23*, 1089-1132.

Kuperman, V., Bertram, R., & Baayen, R.H. (2009). Processing trade-offs in the reading of Dutch derived words. *Journal of Memory and Language*, 62, 83-97.

Laudanna, A., Burani, C., & Cermele, A. (1994). Prefixes as processing units. *Language and Cognitive Processes, 9*, 295-316.

Lefton, L.A., Nagle, R.J., Johnson, G., & Fisher, D.F. (1979). Eye movement dynamics of good and poor readers: Then and now. *Journal of Reading Behavior, 11*, 319-328.

Levin, H., & Buckler-Addis, A. (1979). *The eye-voice span*. Cambridge: MIT Press.

Liberman, I.Y. (1973). Segmentation of the spoken word and reading acquisition. *Bulletin of the Orton Society, 23*, 65–77.

Liberman, I.Y., Shankweiler, D.P., Fischer, F.W., & Carter, B. (1974). Reading and the awareness of linguistic elements. *Journal of Experimental Child Psychology, 18*, 201–212.

Lindeman, J. (1998). *ALLU: Ala-asteen Lukutesti [ALLU: Reading test for elementary school]*. Turku, Finland: University of Turku, Center for Learning Research.

Liversedge, S.P., Rayner, K., White, S.J., Vergilino-Perez, D., Findlay, J.M. & Kentridge, R.W. (2004). Eye movements when reading disappearing text: Is there a gap effect in reading? *Vision Research, 44*, 1013-1024.

Lundberg, I., Frost, J., & Petersen, O.-P. (1988). Effects of an extensive program for stimulating phonological awareness in preschool children. *Reading Research Quarterly, 23*, 263-284.

Maïonchi-Pino, N., Magnan, A., & Écalle, J. (2009). Syllable frequency effects in visual word recognition: Developmental approach in French children. *Journal of Applied Developmental Psychology*, 31, 70-82.

McConkie, G.W., Kerr, P.W., Reddix, M.D., & Zola, D. (1988). Eye movement control during reading: I. The location of initial eye fixation locations on words. *Vision Research, 28,* 1107-1118.

McConkie, G.W., & Loschky, L.C. (2002). Perception onset time during fixations in free viewing. *Behavioral Research Methods, Instruments, and Computers, 34,* 481-490.

McConkie, G.W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics, 17,* 578-586.

McConkie, G.W., Zola, D., Grimes, J., Kerr, P.W., Bryant, N.R., & Wolff, P.M. (1991). Children's eye movements during reading. In J.F. Stein (Ed.), *Vision and visual dyslexia* (pp. 251-262). London: Macmillan Press.

Morrison, R.E., & Inhoff, A.W. (1981). Visual factors and eye movements in reading. *Visible language, 15,* 129-146.

Moscoso del Prado Martín, F., Bertram, R., Häikiö, T., Schreuder, R., & Baayen, R.H. (2004). Morphologically family size in a morphologically rich language: The case of Finnish compared with Dutch and Hebrew. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1271-1278.

Nation, K. (2008). Learning to read words. *The Quarterly Journal of Experimental Psychology, 61,* 1121-1133.

Nevala, J., & Lyytinen, H. (2000). *Sanaketjutesti* [Word chain test]. Jyväskylä, Finland: Niilo Mäki Instituutti ja Jyväskylän yliopiston lapsitutkimuskeskus [Niilo Mäki Institute and Child Research Center of University of Jyväskylä].

Pollatsek, A., & Hyönä, J. (2005). The role of semantic transparency in the processing of Finnish compound words. *Language and Cognitive Processes, 20,* 261–290.

Pollatsek, A., Lesch, M., Morris, R.K., & Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 148-162.

Pollatsek, A., Reichle, E.D., & Rayner, K. (2006). Tests of the E-Z Reader model: Exploring the interface between cognition and eye-movement control. *Cognitive Psychology, 52,* 1–52.

Poskiparta, E., Niemi, P., & Vauras, M. (1999). Who benefits from training in linguistic awareness in the first grade, and what components show training effects? *Journal of Learning Disabilities*, 32, 437-446.

Rabin, J., & Deacon, H. (2008). The representation of morphologically complex words in the developing lexicon. *Journal of Child Language,* 35, 453-465.

Radach, R., Huestegge, L., & Reilly, R. (2008). The role of global top-down factors in local eye-movement control in reading. *Psychological Research, 72,* 675-688.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7,* 65-81.

Rayner, K. (1979). Eye guidance in reading: Fixation locations within words. *Perception, 8,* 21-30.

Rayner, K. (1985). The role of eye movements in learning to read and reading disability. *Remedial and Special Education, 6,* 53-60.

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology, 41,* 211-236.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372-422.

Rayner, K., Liversedge, S.P., White, S.J. & Vergilino-Perez, D. (2003). Reading disappearing text: Cognitive control of eye movements. *Psychological Science, 14,* 385-388.

Rayner, K., & McConkie, G.W. (1976). What guides a reader’s eye movements. *Vision Research, 16,* 829-837.

Rayner, K., Liversedge, S.P., & White, S.J. (2006). Eye movements when reading disappearing text: The importance of the word to the right of fixation. *Vision Research, 46,* 310-323.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading.* Englewood Cliffs, NJ: Prentice Hall.

Rayner, K., Sereno, S.C., & Raney, G.E. (1996). Eye movement control in reading: a comparison of two types of models. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1188-1200.

Rayner, K., White, S.J., Kambe, G., Miller, B., & Liversedge, S.P. (2003). On the processing of meaning from parafoveal vision during eye fixations in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds). *The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research,* pp. 213-234. Amsterdam: Elsevier.

Reichle, E.D., Pollatsek, A., Fisher, D.L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105,* 125-157.

Reichle, E.D., Rayner, K., & Pollatsek, A. (2003). The E-Z Reader model of eye movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences, 26,* 445–526.

Reilly, R.G., & Radach, R. (2003). Foundations of an interactive activation model of eye movement control in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.). *The mind’s eye: Cognition and applied aspects of eye movement research,* pp. 429-455. Oxford: Elsevier.

Reilly, R.G., & Radach, R. (2006). Some empirical tests of an interactive activation model of eye movement control in reading. *Cognitive Systems Research, 7,* 34-55.

Schiller, N.O. (2000). Single word production in English: The role of subsyllabic units during phonological encoding. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 26,* 512-528.

Schreuder, R., & Baayen, R.H. (1997). How complex simplex words can be. *Journal of Memory and Language,* 37, 118-139.

Seidenberg, M. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading.* Hillsdale, NJ: Erlbaum.

Seidenberg, M., & McClelland, J. L. (1989). A distributed, developmental model of visual word recognition and naming. *Psychological Review,* 96, 523-568.

Seymour, P.H.K., Aro, M., & Erskine, J.M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology,* 94, 143-174.

Share, D., & Levin, I. (1999). Learning to read and write in Hebrew. In M. Harris & G. Hatano (Eds.). Learning to read and write: A cross-linguistic perspective (pp. 89-111). Cambridge, UK: Cambridge University Press.

Stanovich, K.E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21,* 360-407.

Taylor, S.E. (1965). Eye movements while reading: Facts and fallacies. *American Educational Research Journal, 2,* 187-202.

Trammell, R.L. (1993). English ambisyllabic consonants and half-closed syllables in language teaching. *Language Learning, 43*, 195-238.

Trauzettel-Klosinski, S., Koitzsch, A.M., Dürrwächter, U., Sokolov, A.N., Reinhard, J., & Klosinski, G. (in press). Eye movements in German-speaking children with and without dyslexia when reading aloud. *Acta Ophthalmologica.*

Vitu, F., McConkie, G.W., Kerr, P., & O'Regan, J.K. (2001). Fixation location effects on fixation durations during reading: An inverted optimal viewing position effect. *Vision Research, 41*, 3513-3533.

White, S.J. (2008). Eye movement control during reading: Effects of word frequency and orthographic familiarity. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 205-223.

White, S.J., Bertram, R, & Hyönä, J. (2008). Semantic processing of previews within compound words. *Journal of Experimental Psychology: Learning, Memory & Cognition, 34*, 988-993.

White, S.J., Rayner, K., & Liversedge, S.P. (2005). Eye movements and the modulation of parafoveal processing by foveal processing difficulty: A re-examination. *Psychonomic Bulletin & Review, 12*, 891-896.

Yap, M., & Balota, D.A. (2009). Visual word recognition of multisyllabic words. *Journal of Memory & Language, 60*, 502-529.

Ziegler, J.C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, 131, 3-29.

Zoccolotti, P., De Luca, M., Di Pace, E., Gasperini, F., Judica, A., & Spinelli, D. (2005). Word length effect in early reading and in developmental dyslexia. *Brain and Language, 93*, 369-373.

APPENDIX:
THE ORIGINAL PUBLICATIONS