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The dynamics of reading in non-Roman writing systems: a Reading and Writing Special Issue

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Abstract This paper provides a short overview of current issues in research on continuous reading in non-Roman orthographies. At the same time it also serves as an introduction to the present Reading and Writing Special Issue on this topic. The main questions examined in the contributions to this volume are closely related to issues that have been central to research debates on reading in English, German and French. However, we argue that these innovative approaches to the dynamics of reading in Chinese, Japanese and Korean go far beyond a simple comparative research strategy. Instead, by illuminating phenomena like word segmentation, parafoveal processing and semantic analysis from their unique perspectives, they provide valuable insights into the more general question of to what extent information processing in reading is universal as opposed to language specific. Moreover, we expect that these initial studies will trigger more basic research on non-alphabetic reading, providing a foundation for useful application.

Keywords Reading · Non-Roman writing systems · Chinese · Korean · Japanese · Eye movements

Introduction

Writing systems are a uniquely human artifact, the product of a confluence of many constraints: the nature of the language whence they have arisen, limitations of human perception and memory, the uniqueness of regional history and culture, to

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name a few. For a considerable portion of the approximately 5,000 years of writing's existence, the skills of inscribing and deciphering were the preserve of the elite (Harris, 1989). However, with the technological innovations of movable type printing in Europe and the spread of large scale, compulsory education, mass literacy came of age in Europe around the middle of the 19th century (Vincent, 2000). While movable type printing was first invented in China almost 400 years prior to Gutenberg and again in Korea contemporaneously with Gutenberg, it was the combination of an alphabetic writing system and movable type that was crucial to its widespread adoption.

Because reading is an acquired skill involving the decoding of patterns of visual stimulation into a linguistic and ultimately a conceptual representation it has proven a popular experimental domain for the controlled study of the interplay of perception, language, and cognition. As Huey (1908) observed in his seminal work "The Psychology and Pedagogy of Reading" first published just over a century ago, to understand reading fully would require a deep understanding of the functioning of the brain as a whole. While Huey's ultimate goal remains elusive to this day, we have made considerable progress in developing a deeper understanding of many of the components of the reading process.

One particularly successful line of attack has been the development of computational models of reading, particularly illuminating the dynamics of information processing in reading on the basis of eye movement data (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reilly & Radach, 2006). Notwithstanding their evident success, they have been limited in their generality by their predominant focus on Roman-derived writing systems. Moreover, until fairly recently there has been a dearth of empirical studies of continuous reading on non-Roman writing systems. In contrast to languages like English, German and French there is very little literature on visual, orthographic, lexical and sentence level processing in the many alternative writing systems. This is not only hampering the development of a comprehensive psycholinguistic understanding of these written languages, it also precludes analysis of how their features give rise to differential effects on reader performance. This, in turn, creates difficulties in the transfer of research findings into the educational field analogous to the increasingly widespread application of such knowledge to European orthographies (see Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001, for a seminal example). Looking at the processing of isolated words, there is already a developing body of literature comparing different written (alphabetic) languages (Ziegler & Goswami, 2005; Goswami, 2009), but obviously this development needs to be complemented by similar efforts in the domain of continuous, sentence and text-level reading.

The present special issue of Reading and Writing had its origins in a symposium on reading non-Roman writing systems held as part of the European Conference on Eye Movements in 2009 (ECEM 2009) in Southampton. Its aim was to address some of the shortcomings in writing system coverage and to throw an informative light on some contentious issues of debate in current comparative reading research. Several papers in this issue are based on or related to presentations held at the symposium, while others have been solicited from ongoing research projects that we felt are well-suited to make substantial contributions to ongoing debates.

Now it should be noted that we are not in any way claiming to provide a representative coverage of the world's approximately 80 extant writing systems (Everson, 2002). Nonetheless, our selection is broadly representative of several main *types* of modern writing system. Included are papers on Chinese, a largely logographic script (see below, for a more precise description), Korean, a rather unique alphabetic-syllabic system, and Japanese, a combination of Chinese-derived ideography and two syllabaries.

The research topics examined in the contributions to the present volume have their origin in the more mainstream research on Roman writing systems, particularly in work focusing on English, German and French. However, as will be apparent below, addressing these issues in alternative writing systems not only extends the scope of research to encompass very important international communities of reading and writing, but equally importantly it allows seeing the issues of research from radically different perspectives. This allows us to address the fundamental question of to what degree the processing of written language is governed by universal principles as opposed to shaped by properties of specific languages and writing systems.

The pre-eminent research topic addressed in this context relates to the nature and extent of spatially distributed word processing within non-Roman typographies. The contributions to the present special issue add to this growing body of knowledge on the topic in several innovative ways. Most of this work has been carried out in Chinese, so that a few words characterizing this important writing system seem in order. Traditionally, written Chinese is considered a largely logographic system, with characters composed of strokes which in turn comprise basic visual features such as lines, curves and dots (see Zang, Liversedge, Liang, Bai & Yan , 2011, for a concise and informative discussion). Importantly, characters can often be divided into sub-characters generally referred to as radicals, which in many cases carry phonological and semantic information (Hoosain, 1991). In a very general way, Chinese characters can be seen as similar to morphemes in the Roman writing system, but it is also not uncommon to characterize the Chinese writing system as a large and phonetically imprecise syllabary with significant visual and semantic elements (Mair, 1996). An important convention in the writing of Chinese is that there are no spaces between words, leading to the fascinating question of how, assuming that the word is a central unit of linguistic processing, the boundaries between such units can be determined within the time constrains of fluent reading. That skilled readers of Chinese are indeed very efficient in solving this problem seems evident from the fact that reading rates for equivalent text in English and Chinese are nearly identical (Sun & Feng, 1999), suggesting that the rate of information extraction is basically equivalent (see also Inhoff & Liu, 1998; Sun, Morita, & Stark, 1985).

Character and word processing

A substantial amount of research effort has been invested in identifying the factors that determine the difficulty of Chinese character and word processing. As an example, Yan, Tian, Bai and Rayner (2006) have shown that fixation time measures were sensitive to both word and character frequency, and that these frequency effects were similar in size to those reported in numerous studies for reading in English. More specifically, when reading two character words, character frequency modulated the word frequency effect, with the first character having a greater effect than the second, while, on the other hand, the effect of character frequency was less pronounced with high frequency target words.

In their most recent work on this topic, Yan, Bai, Zang, Bian, Lei, Qi, Rayner and Liversedge (this volume) go a step further and examined in detail how the visual composition and complexity of characters determines their recognition. This question was first examined by Just and Carpenter (1987), who reported that gaze durations are longer on characters containing a larger number of strokes. Similarly, Yang and McConkie (1999) showed that the complexity of characters within two-character words (again expressed as number of strokes) affected gaze duration, fixation probability and the number of refixations on a word.

Yan et al. add a significant new angle to this line of work, addressing the overall shape of characters and the sequence of stroke writing as potentially important features. To this end, they systematically removed different parts of characters. There was no measurable effect when up to 15 % of strokes were removed, indicating some level of redundancy in character composition. Anything above 30 %, however, had a significant impact on various reading time measures. Interestingly, when the overall shapes of characters were retained, the impact of stroke removal was minimized. Moreover, the removal of different character components had a differential effect on processing, with removal of beginning strokes causing the most disruption. This latter finding has potentially interesting implications. It could be due to the fact that the upper-left character region is more visually informative or because this is also the part of the character that is written first. In the latter case, the authors suggest that there may be some interaction between the motor programs involved in writing Chinese characters and the visual processing routines. Indeed, a meta-analysis of brain imaging studies by Tan, Laird, and Li (2005) found a significantly greater involvement of areas of the motor cortex in Chinese as compared to alphabetic reading.

The issue of stroke complexity is again taken up in the article by White, Hirotani, and Liversedge (this issue), this time in the context of reading in Japanese. The Japanese writing system is a mixture of Chinese-derived kanji characters, and characters from two syllabaries, hiragana and katakana, that are used to represent syntactic particles and borrowed words, respectively. Given the economic and cultural importance of Japan it is rather surprising that there appears to be very little published experimental research on reading in Japanese. To our knowledge there are only very few articles on continuous reading using eye movement methodology, with topics ranging from basic eye movement control (Osaka, 1992) to word segmentation in a mixed writing system (Kajii, Nazir, & Osaka, 2001; Sainio, Hyönä, Bingushi, & Bertram, 2007) and most recently, parafoveal orthographic processing (Perea, Nakatani, & van Leeuwen, 2011).

White, Hirotani and Liversedge (this issue) specifically examine the effect of the orthographic structure of Japanese words on reading times as well as landing positions of incoming saccades. The latter issue has received considerable attention in the literature on reading in European languages. In alphabetic scripts, incoming saccades tend to cluster at a preferred viewing position (Rayner, 1979), about halfway between the beginning and the center of words. Furthermore, it has been shown that the eyes move further into words beginning with letter sequences of high orthographic regularity (e.g., Hyönä, 1995; White & Liversedge, 2004). Radach, Inhoff and Heller (2004) demonstrated that the morphological structure of target words (the presence vs. absence of a morpheme boundary) did not modulate the saccade amplitude effect, presumably because results of morphological processing do not become available early enough.

Similarly, White et al. (this issue) demonstrate that structural properties of Japanese two-character words appear to have very little effect on saccade landing positions. They embedded words consisting of either one or two kanji characters in sentences so that the target word was embedded with hiragana characters. In a comparison of two-character kanji words with a region consisting of the first character plus the following hiragana character, no difference in saccade parameters emerged, suggesting that the length of a kanji word in the parafovea is not taken into account in saccade targeting. However, when the first character of a two character kanji word is visually complex, this character has a higher probability of being fixated. Together, these findings confirm the absence of a preferred viewing position in the reading of Japanese script (Kajii et al., 2001) and are compatible with a very simple saccade targeting routine of sending the eyes to the first or second characters of any kanji character sequence visible in the parafovea (see Reilly & O'Regan, 1998, for a similar suggestion in alphabetic reading). These findings blend nicely with the ongoing discussion on how saccade targeting is controlled in Chinese and future research will have to show whether targeting strategies are as flexible in Japanese as has been recently suggested in detailed analyses of Chinese reading (Yan, Kliegl, Richter, Nuthmann, & Shu, 2010).

Parafoveal word segmentation

Assuming that readers in non-European writing systems have effective mechanisms for word segmentation, the question arises of how this segmentation process may work and how much of it can be accomplished as part of spatially distributed processing, that is while a target word is still seen in the parafovea. Research on this issue is often conducted using the so-called boundary paradigm pioneered by Rayner (1975; see also Rayner, Well, Pollatsek, & Bertera, 1982). This technique involves the designation of a notional boundary, usually between word position n and word position $n + 1$. When the eye crosses the boundary, the sequence of characters at word position $n + 1$ (the mask) is replaced with a new sequence of characters (the target). The replacement occurs when the eye is in motion, so the change usually goes unnoticed by the reader. The target is usually a legitimate word, while the mask can be anything from random letters to the target word itself (as a control condition).

By manipulating what information at position $n + 1$ is available to the reader prior to crossing the boundary, we have a very powerful tool for exploring the nature and time course of visual and linguistic processing on every level, including orthography, phonology and semantics. In recent research on English, German and

French, the primary focus of theoretical concern has been centered on two dimensions, the *extent* of parafoveal processing (e.g., from word $n + 1$ or $n + 2$ to the right of the current fixation) and the *nature* of the information processed (e.g., lexical vs. semantic information). Studies focusing on both of these dimension will be discussed below for non-European writing systems.

A typical preview effect is the so-called "preview benefit" whereby having access to a valid preview of word $n + 1$ (i.e., where mask and target are identical), causes a reduction in viewing time on $n + 1$ compared to when there has been an invalid preview. In the latter case, an invalid preview might have been a semantically related word, a phonologically similar word, an orthographically related word, an orthographically regular non-word, a random string of letters, a string of Xs, and so on. Preview benefit will vary systematically depending on the type of preview, but tends to be of the order of several 10s of milliseconds and is a robust phenomenon across a range of languages and writing systems (see Schotter, Angele, & Rayner, 2012, for a comprehensive review).

Coming back to the issue of parafoveal word segmentation, Yen, Radach, Tzeng, and Tsai (this issue) examine the hypothesis that statistical cues for word boundaries may be a major factor contributing to word segmentation in the parafovea. As an example, the presence of a character that is often in the word-final position may be taken to indicate that a word boundary to its right indeed exists. On the other hand it may require extra effort to determine a word boundary when the word-final character is generally used as a word beginning. This logic is derived from similar analyses with compound words in German (Inhoff, Radach, & Heller, 2000) and Finnish (Bertram, Pollatsek, & Hyönä, 2004).

In one of their experiments, Yen et al. (this issue) used the boundary technique (see below) to manipulate the word-diagnostic value of the second character of a two-character word seen in the parafovea and found significant differences in word-viewing times on the target. On the other hand, there was no effect of overlapping character ambiguity (Inhoff & Wu, 2005), indicating a level of robustness in the early parsing of character sequences. Taken together, results suggest that within-word positions had a substantial influence during character-to-word assignment, which was mainly verified during foveal processing. In the discussion of these results it should be taken into account that only a minority of Chinese characters can unambiguously signal a word boundary. According to Yen, Radach, Tzeng, Hung, and Tsai (2009), only about 18 % of 5,915 unique characters appear in only one within-word position, including single-character words, the beginning characters, or the ending characters of multi-character words, while about 49 % of characters are used in all within-word positions. Thus it makes perfect sense that an early parafoveal parsing of word identity may take the form of an educated guess rather than a firm commitment that might have to be revised later.

Spatially distributed lexical processing

After establishing that spatially distributed processing in Chinese operates on both the character and word level, the next issue to address is the spatial extent within which such processing can occur. One of the reasons this issue is currently so much in focus is because it serves as a crucial differentiating test of the two dominant classes of computational models of eye movement control in reading. An essential difference between the two classes of model is in how processing resources are allocated. One class (e.g., E-Z Reader, Reichle et al., 1998) argues that 'attention' shifts somewhat like a spotlight and does so as a direct function of word processing. The other class (e.g., SWIFT, Engbert et al., 2005; Glenmore, Reilly, & Radach, 2006) considers visual processing resources as a gradient spread over the visual field with its peak around the fovea. In the latter case, several words can be processed simultaneously and the progression of the eye is not dependent directly on linguistic processing. In the former case, however, words are processed sequentially in a fixation and the progression of the attentional spotlight is strictly coupled to the time-course of word processing during the fixation, as is the triggering of progressive saccades to the next word to the right.

In this context it is critical whether parafoveal information can be acquired from word $n + 2$ while word n is being fixated. If this were the case, it could be seen as a 'strong falsifier' for the sequential control view (Jacobs, 2000), as there is very little scope for a one-word lexical processing window to move this far out without contradicting core principles of a model like E-Z reader (see for example Radach, Reilly, & Inhoff, 2007; Schotter et al., 2012, for recent discussions). The issue of $n + 2$ preview effects has been studied extensively over the last few years, with some studies reporting negative results (Angele, Slattery, Yang, Kliegl, & Rayner, 2008; Angele & Rayner, 2011; McDonald, 2006; Rayner, Juhasz, & Brown, 2007), while others present evidence in favor of distant parafoveal processing (Kliegl, Risse, & Laubrock, 2007). It should be noted that the evidence that is in harmony with $n + 2$ preview effects comes exclusively from studies that have created optimal conditions for the effect to occur, for example, by using three-letter $n + 1$ words or making these words high frequency and/or highly predictable. It therefore appears that parafoveal processing beyond word $n + 1$ is at the very limit of processing within the perceptual span and may occur only if enough resources are available during a given fixation.

In the case of Chinese reading, however, it appears possible that here parafoveal processing beyond word $n + 1$ is more common. As discussed above, Chinese script comprises a compact set of characters written in a delimited area irrespective of their complexity. Therefore, a significant amount of visual information is compressed into a small and regular space. The advantage of this from the reader's perspective is that the region in which orthographic and lexical information is acquired may be more or less constant, since the average word length of Chinese words does not vary much beyond two characters. So Chinese is to some extent a natural control for word length and the acuity decline associated with longer words extending into the parafovea.

Indeed, $n + 2$ preview effects have been reported for Chinese reading by Yang, Wang, Xu and Rayner (2009). In the present volume, Yang, Rayner, Li, and Wang re-investigate the issue. Instead of a high frequency function word, as in their prior work, they now placed a relatively low frequency word in front of the critical target word. Under these circumstances a preview effect from word $n + 2$ no longer materialised, suggesting an interaction of $n + 1$ and $n + 2$ processing. The interesting conclusion that can be drawn from this work is that the words within the perceptual span compete for resources and that a sufficient amount of such resources become available for more remote words such as $n + 2$ only when the processing demands for more proximal words such as n and $n + 1$ are relatively low. The authors emphasise that this interpretation is in line with recent work by Yan, Kliegl, Shu, Pan, and Zhou (2010), who also suggested that processing load from foveal words modulates the perceptual span in Chinese.

Semantics and sentence-level processing

In addition to the issue of how far onto the periphery spatially distributed character and word processing can extend, the issue of what information can be processed in this way has become the focus of scientific debate. A central question in these discussions is whether high-level information such as semantics or sentence-level syntax may be acquired parafoveally. With respect to alphabetic writing systems, most of the evidence is not in support of parafoveal semantic processing, as there has been no evidence of viewing time benefits from semantically related previews using the boundary paradigm. In a typical experiment, Rayner, Balota and Pollatsek (1986) compared semantically related parafoveal preview target words (e.g., *tune* as a preview for *song*) with similar non-word previews (sorp), nonrelated words (door) and an identical word baseline. There was no facilitation from the semantically related preview relative to the unrelated word condition, even though a standard semantic priming effect was obtained in a response time experiment using the same word pairs. The likely explanation for this pattern of results is that during sentence reading semantic information becomes available too late in the time course of word processing (see Rayner, White, Kambe, Miller, & Liversedge, 2003, for a detailed discussion). More recently, Hohenstein, Laubrock, and Kliegl (2010) reported German reading data suggesting a preview effect when a semantically related parafoveal word was available during an early stage of a fixation on the pre-target word. More research will be required to confirm these results, and at this point it appears possible that a pattern of findings may emerge where parafoveal extraction of semantic information occurs under specific, favorable conditions.

In contrast to the situation described above, there is considerably more evidence for parafoveal semantic processing effect in Chinese reading and indeed this is evident from several of the special issue papers. Yan, Richter, Shu, and Kliegl (2009) first reported parafoveal preview effects on fixation and gaze duration for Chinese preview characters which were semantically related to targets. In addition, they also demonstrated an effect of parafoveal semantic processing (generally referred to as a parafovea-on-fovea effect) on the duration of the last gaze before entering the target string. A similar study by Yan et al. (2010) extended the paradigm to include targets in word position $n + 2$, finding that here only identical compared to unrelated-word preview led to shorter viewing times on the target word. The work by Yan, Risse, Zhou, and Kliegl (this issue) combines this approach with the time course analysis introduced by Hohenstein et al. (2010). Their data suggest that semantic preview benefit in Chinese occurs in an early time window during the fixation of the pre-boundary word. Among other relevant results, they found that semantic preview benefits for word $n + 1$ are only observed when there has been a shorter than average fixation on word *n,* the pre-boundary word. Yan et al. (this issue) suggest that this may be due to a facilitation-then-inhibition type of effect from the semantically related preview. If fixations on the pre-boundary word are long enough, facilitation of the target turns into inhibition. While these results are consistent with earlier fast priming studies (e.g., Lee, Rayner, & Pollatsek, 1999), they are difficult to account for within current reading models, even those that argue for parallel processing of several words in a fixation.

The scope of research on spatially distributed semantic processing is substantially extended by Yang, Wang, Tong, and Rayner (this issue), who combined semantic relatedness between preview and target with a potentially important high-level factor, the contextual plausibility of the preview within the current sentence. It turns out that the plausibility of the preview yielded a stronger preview benefit than semantic relatedness, though the latter did also have an impact on short single fixations. This finding fits very nicely with that of Yan et al. above, who also reported that semantic preview benefit tended to be found for short previewing fixations. Taken together, the two papers on the issue of semantic processing included in the present issue provide robust evidence that semantic information is regularly processed from parafoveal words within the relatively compact perceptual span in Chinese reading.

The paper by Kim, Radach, and Vorstius (this issue) presents evidence of high-level parafoveal processing in Korean reading. The Korean writing system, Hangul, is interesting from the perspective of reading research in that it is spatially compact, similar to Chinese, but unlike Chinese is alphabetic in nature. The letters of the Hangul alphabet are arranged in blocks, which, in turn, usually correspond to syllables. This system provides a quasi-control for some of the orthographic features of Chinese and allows us to ask the question whether the higher-level preview phenomena identified for Chinese are a function of the spatial features of Chinese or something more intrinsic to Chinese orthography. The study by Kim et al. (this issue) manipulated case markers unique to Hangul (and, in a similar form, Japanese) whereby particular character suffixes are used to indicate the case role of a noun (e.g., subject, object, or topic). In one condition a boundary paradigm was used to present incorrect case makers in terms of syntactic category, effectively creating a semantic mismatch between preview and target. Importantly, all previews were perfectly legal, so that their appropriateness was driven exclusively by contextual information.

Results indicated that previews of both phonologically and syntactically inappropriate case markers caused elevated reading times of the target word, specifically for late viewing time measures (gaze duration and total viewing time). Since case markers are a frequent occurrence in Hangul it can be concluded from this work that skilled readers of Korean routinely acquire high-level linguistic information available in the parafovea. In addition to the spatial compactness of the script this may be related to the fact that Korean is a left-branching language, where information critical for the assignment of meaning is often delayed (e.g., when a direct object is placed before a verb). Thus there is high demand for disambiguating information early in a sentence. Since Korean shares this structural feature with, among others, Turkish, Japanese, Tamil and Basque, it is tempting to speculate that there might a whole family of written languages in which the early processing of semantic and/or syntactic information is part and parcel of routine reading behavior.

Challenges for models of continuous reading

Taken together, the studies included in the present issue present a more complex and more nuanced picture of the early stages of information processing in reading than one we might have obtained from just analysing data from Roman-derived alphabetic writing systems. The picture emerging is of a subtle relationship between the nature of the visual stimulus, properties of the underlying language, and eye movement control. With space-delimited words, as in English, the mechanism for progressing the eye could afford to be quite crude. For example, simulating a strategy like "go to the next large blob in the right parafovea", can deliver a surprisingly good approximation of eye movements in English or French (Reilly & O'Regan, 1998). With evidence of sensitivity to finer spatial resolution information among readers of non-Roman scripts, we need a more sophisticated framework for thinking about how to combine all levels of information that feed into the decision where and when to move the eye to the next target. A promising candidate, in this respect, may be the Bayesian estimator model of eye movement control recently described by Engbert and Krugel (2010).

While the contribution of various computational models to our understanding of reading over the last 20 years has been crucial, their signal success may be coming at a price. For good or ill, the models have dictated much of the recent research agenda in the field of eye movement control in reading. Of more concern, perhaps, is that the engagement between competing models has also dictated the research agenda. Consequently, data that none of the models can adequately address may tend to get ignored in favour of crucial instances of difference between models. The parafoveal preview phenomenon is a case in point, where evidence of $n + 2$ preview and semantic preview tend to favour one model over another. However, in the bigger scheme of things these differences may not be as crucial as, say, dealing with word-segmentation in scripts that have no explicit word boundaries. But, since none of the current models can adequately account for this phenomenon, it tends to get pushed off the research agenda.

Without exception, current computational models of reading ignore this critical issue of word segmentation and assume that words are presented to their respective word recognition engines conveniently delimited (Engbert et al., 2005; Reichle et al., 1998; Reilly & Radach, 2006). For example, in an application of the E-Z Reader model to Chinese, the modelers provided their processing engine with pre-segmented text (Rayner, Li, & Pollatsek, 2007), thus circumventing a major feature of their target language. Until recently, it had been assumed that without the help of spaces, readers of unspaced writing systems fell back on a default strategy comparable to that found for readers of unspaced English (e.g., Rayner, Fischer, & Pollatsek, 1998). While this is clearly true for English, the evidence from conventionally unspaced writing systems has proven to be a little different. There is now substantial evidence that readers of Chinese are able to direct saccades close to the center or beginning of words without the help of spaces (e.g., Li, Liu & Rayner, 2011; Yan et al., this issue;). Moreover, there is evidence that Chinese readers also demonstrate a sensitivity to word-initial character statistics (Yen et al., this issue). Both of these findings also apply to Thai, an unspaced alphabetic writing system, where Reilly, Aranyanak, Yu, Yan, and Tang (2011) have shown the existence of a preferred viewing position that is modulated by character frequency at word boundaries. If this is a consistent pattern across unspaced writing systems, it presents significant challenges to current models of information processing and eye movement control in reading.

Another key issue not touched on by the papers here is the degree to which reading processes adopted for a given writing systems are part of the repertoire of all readers or are strategies developed for specific information constraints associated with that writing system. A clue to the answer may come from the work of Liu, Dunlapp, Fiez, and Perfetti (2007) who used brain-imaging data to compare readers of English who were taught to read a small number of Chinese characters with bilingual readers of Chinese and English. The basic results of this study were that the brains of readers accommodate in rather particular ways to the task demands of a writing system. However, the accommodation does not necessarily have symmetric consequences, since they conclude that readers of Chinese may possess more general-purpose reading skills than readers of alphabetic systems. Evidence from the meta-analysis of brain imaging of Chinese readers by Tan, Laird, and Li (2005), mentioned earlier, also suggests writing-system specific brain adaptions particularly implicating handwriting as an important component skill for reading Chinese.

Issues for future research

The papers in the present special issue make substantial contributions to the developing body of research on the dynamics of reading in non-Roman writing systems. Even though the main issues studied were derived from prior work on European alphabetic systems, we believe that these studies go far beyond a simple comparative research strategy. Instead, investigating phenomena like word segmentation, parafoveal processing and semantic analysis from their unique perspectives provides valuable insights into the more general question as to what extent information processing in reading is universal as opposed to language specific.

On this more general level, we can conclude that the order and coordination of processing stages in reading can be remarkably flexible. When a writing system does not provide a visual demarcation of word boundaries (see our discussion above in the context of model development), the identity of character strings as potential words cannot be derived from low-level visual information. In this case, the segmentation of words becomes part of the recognition process, either via the (limited) use of cues derived from positional characters frequencies (Yen et al., this volume) or as part of regular character processing within the perceptual span (Yan et al., this volume; Yang et al., this volume). The less determined nature of word processing in languages like Chinese or Thai has another interesting consequence:

saccade control becomes much more flexible, and the Gaussian saccade landing positions typical for Roman alphabetic reading now appear as a special case among other possible targeting strategies (Li et al., 2011; Li, Rayner, & Cave, 2009; Yan et al., 2010). A similar conclusion might be drawn from the results on the parafoveal processing of syntactic case markers in Korean reported (Kim et al., this issue). We have speculated above that there may be substantial variation in the degree to which various written languages require immediate semantic or syntactic input in the service of effective comprehension. If so, this may in turn lead to different degrees to which available processing resources are used for such high-level parafoveal processing.

The articles in this issue focus on a relatively small sample of non-European writing systems (Chinese, Korean, and Japanese). Even within the Roman alphabetic writing system, the vast majority of research contributions focus on a small number of languages such as English, German, French and Spanish. In addition, there is a small number of studies on continuous reading in other alphabetic writing systems like Hebrew (e.g., Deutsch, Frost, Pelleg, Pollatsek, & Rayner, 2003), and, most recently, in Arabic (Abubaker, McGowan, White, Jordan, & Paterson, 2011). Another very interesting written language is Thai, which uses a complex writing system composed of consonants, vowels and special characters written without spaces. Reilly et al. (2011) have recently reported results of a study comparing the reading of similar texts in Thai and Chinese. They have proposed that readers of Thai and Chinese are operating under uncertainty about word location and use a default targeting heuristic (e.g., make an average length saccade) that is modulated by incoming sensory information. This modulation can come from potentially any statistically reliable source of constraint. In both Thai and Chinese, the degree to which word-initial characters are predictive of a word boundary appears to be used to improve the targeting of words. They suggest that other low-level statistical properties of the input might also have additive effects in reducing uncertainty and increasing the accuracy of saccades.

However, looking at the body of work accumulated at this point, it is obvious that, despite impressive progress, we are still far away from any comprehensive understanding of how the differences between languages and writing systems shape the dynamics of reading. In the broader scheme of reading research, work on this topic is still in its infancy, with vast and culturally eminent parts of human culture (such as the diverse writing systems in India) not even mentioned. The deficit is not only apparent in relation to the number of languages covered, it is also clear that the scope of this work needs to be extended.

Looking back to the main body of work on Roman alphabetic orthographies, experimental research on continuous reading has had tremendous success, but of course there are also shortcomings and deficits that should be addressed in future research. Some of these issues have been discussed in detail by Radach and Kennedy (2004), in an introduction and commentary paper quite similar to the present one, but focused on alphabetic reading. In addition to the obvious drive towards integration of empirical work with modeling (see above), they discussed a number of unresolved (and often overlooked) methodological issues (e.g., Inhoff & Radach, 1998; Inhoff & Weger, 2003), emphasized the need for integration with work on single word recognition (see Grainger, 2008, for a recent overview), suggested more work from a developmental perspective, and argued for a stronger focus on individual variations in reading and effects of task demands.

In our opinion, the last mentioned issue is going to be especially fruitful for the development of the field. As an example, Radach, Huestegge, and Reilly (2008) have shown that varying the depth of processing via application of different types of comprehension questions has profound effects on the dynamics of reading. Going a step further, Wotschack and Kliegl (2011) demonstrated that intra-individual variation of reading strategy can modulate the type of spatially distributed word processing that has been the focus of so many of the contributions to the present special issue. This approach of examining variation within the same reader is a necessary complement of the more established strategy of examining inter-individual determinants of information processing. Here, the classic example would be to specify subsamples of readers by their working memory performance and observe differences in oculomotor reading measures (Kennison & Clifton, 1995). Closely related to our present focus on spatially distributed processing is the demonstration by Chace, Rayner and Well (2005) that reading skill as measured by a standard psychometric test modulates parafoveal information acquisition so that less skilled readers show attenuated benefit from parafoveal linguistic information.

In principle, all the points made above fully apply to reading in non-European writing systems. In the case of Chinese there is already a very dynamic development, in which some of the issues discussed above are actively addressed. This is true, as one promising example, in the case of adopting a developmental perspective on dynamic reading (e.g., Chen, Song, Lau, Wong, & Tang, 2003; Feng, Miller, Shu, & Zhang, 2009).

Moreover, the fascinating findings we have discussed may suggest new classes of bilingual experiments that might be carried out. For example, a potentially fruitful line of enquiry would be to follow up on the Perfetti Group's study (Liu et al., 2007), and compare reading performance of native Chinese speakers reading English, and native English speakers reading Chinese. In all this future work, the field should strive towards an integration of experimental, cognitive science grounded work with the much larger stream of work based on psychometric assessments of component processes (Kupermann & Van Dyke, 2011; McConkie, Grimes, Kerr, & Zola, 1991). We hope that such an integrative approach will help avoid a potential slowing of progress due to segmentation along borders of methods and theory. In any case we are certain that the present special issue will trigger more research on reading in non-Roman orthographies, moving us a step closer to a full understanding of a most fascinating skill and providing a foundation for useful application.

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