

Running head: ORTHOGRAPHY AND EYE MOVEMENTS

Orthography and Eye Movements: The Paraorthographic Linkage Hypothesis

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The past decade has witnessed spectacular success in understanding of eye movements during reading. Numerous computational models have been proposed to account for eye movements of skilled readers of English and related orthographies (Engbert, Nuthmann, Richter, & Kliegl, 2005; Feng, 2003; Legge, Klitz, & Tjan, 1997; Pollatsek, Reichle, & Rayner, this volume; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003; Reilly & O'Regan, 1998; Richter, Engbert, & Kliegl, 2006; Risse, Engbert, & Kliegl, this volume; Shillcock, Ellison, & Monaghan, 2000). This volume marks a significant new development as one of the most influential reading eye movement models, the E-Z Reader (Reichle, et al., 1998; Pollatsek et al., this volume), is extended to Chinese, a very different script from English (Rayner, Li, & Pollatsek, this volume; Rayner, Li, & Pollatsek, 2007). Amidst this great achievement and high expectations, it is perhaps time to reflect on the success of current theories and the prospect of a universal theory of reading.

The starting point of this chapter is what I shall call the *trinity of the word*, an often unstated assumption that the word is the basic unit of foveal (and parafoveal) word recognition, reading comprehension, and oculomotor planning. The notion of the word as a common unit linking sub-processes of reading is the common denominator of virtually all eye movement theories. This is obviously a problem for reading unspaced scripts such as Chinese, Japanese, and Latin before the introduction of spaces and punctuations.

This chapter advocates an alternative view that sees skilled reading processes as the optimal exploitation of the writing system in order to achieve maximal reading efficiency. Seen in this light, the *trinity of the word* is a convenient hypothesis, not a theoretical necessity. For linguistic and historical reasons, it works extremely well in English. But its utility ultimately depends on the nature of the *paraorthography* – the use of punctuations and spaces – of a script. The history of paraorthography reveals an intriguing co-evolution between reading processes and

paraorthographic conventions, where medieval readers struggled to adapt to the script but meanwhile constantly invented and adopted new paraorthographic symbols to facilitate oculomotor planning. Underneath the seemingly haphazard historical changes the purpose is unambiguous – to embed clues in the script to optimize the coordination of reading processes.

We conclude the journey, which spans several millennia and disciplines, with the *Paraorthographic Linkage Hypothesis* (PoLH), a synthesis of psychological, linguistic, and historical observations on orthography and eye movements. The gist of the PoLH is that the mechanism of skilled reading is the product of an optimization process, not the other way around. To the extent all scripts provide useful statistical cues in the texts, readers will exploit the information in a way that maximizes reading efficiency, with or without the notion of words.

Words in Reading Eye Movement Models

Here is one way to appreciate the challenge of programming eye movements during reading: An average fixation lasts somewhere between 200 and 250 ms (Feng, 2003; McConkie, Kerr, & Dyre, 1994; Rayner, 1998), during which time the reader has to recognize written symbols in the fovea (and perhaps the parafovea), do syntactic and semantic analyses, and plan the next eye movement. According to Sereno and Rayner (2003), it takes approximately 60 ms for the retinal image to reach the visual cortex, and another 100 ms or so for oculomotor planning. These physiological constraints leave very limited time for visual word recognition and language processing. Meanwhile, ERP evidence suggests that the earliest word frequency and context effects occurs approximately 150 ms after the fixation onset and many syntactic and semantic effects show up much later, around 400 to 600 ms. Your assignment: Fit all these processes into a 200-250 ms fixation.

Obviously, a serial processing strategy will not work. The idea that the eyes randomly sample texts along a line – thus avoiding any linguistic constraints – has also been rejected long ago (Haber, 1976, Rayner, 1978; see also Rayner, 1998). A viable model needs to parallelize visual, oculomotor, and language processes in order to compress processing time. But these processes are naturally interlocked: One needs the output of another to proceed. The knack is to discover what elements can run in parallel and what cues can be used to coordinate these intricate actions.

Words appear to do the trick. Once words are recognized, sentence comprehension seems automatic – reminiscent of the Simple View of Reading (Hoover & Gough, 1990). It suggests that post-lexical processes could be excluded from the 200 ms limit, a major time saver. In addition, spaces between words make saccade programming easier (Juhasz, Inhoff, & Rayner, 2005; Pollatsek & Rayner, 1982). They are also important in foveal word recognition. Word recognition is most efficient at the *optimal viewing position* (OVP), which is generally at the center of the word (O'Regan, 1990; O'Regan & Jacobs, 1992). In continuous reading, McConkie and colleagues (McConkie, Kerr, Reddix, & Zola, 1988) showed that saccades are targeted at word centers, although oculomotor errors can skew the actual landing location (Rayner, 1979).

Theories of reading eye movement control. This review is not intended to be a comprehensive survey of models of reading eye movement control; rather, it illustrates how processing time could be squeezed into a 200 ms or so fixation by exploiting the notion of words in different ways.

A good starting point is the Morrison model. Morrison (1984) hypothesized that words are processed serially, and saccades are programmed to target the next word. In the case the parafoveal word is identified in parafoveal vision while waiting for oculomotor planning, the saccade target may be skipped. Fixation duration is determined by lexical processing time, plus the time to prepare the next saccade, and minus the benefit from parafoveal processing during the previous fixation. The Morrison model achieved two parallel processes. By dropping post-lexical language

processes out of the picture, Morrison implicitly assumed that they run in parallel with other processes. The hallmark of the Morrison theory is the parallelization of parafoveal previewing and oculomotor programming; foveal word recognition and saccade programming remain serial processes.

The E-Z Reader model (Pollatsek et al., this volume; Reichle et al., 1998, 2003) is the latest and most influential extension of the Morrison framework. A prominent change is the proposed $L1/L2^2$ stages in lexical processing. By allowing saccade programming to begin at the completion of $L1$, as opposed to after $L2$ (as in Morrison's model), E-Z Reader allows more overlapping between lexical access and saccade planning. The word is also the basis for saccade programming. The implementation of the OVP effect (the eccentricity variable), for example, awards fixations landed near OVP with addition savings in recognition time. It does inherit from Morrison (1984) the strict serial foveal and parafoveal processing – the covert attention is only moved to the next word in the parafovea when the foveal word recognition is completed.

SWIFT (Engbert et al., 2005; Risse et al., this volume; Richter et al., 2006) introduced two types of parallel processes. First, all words within the perceptual span are activated in parallel. This affords a lot of flexibility to account for potential interactions among words: for example, the parafoveal-on-foveal effect (Kennedy & Pynte, 2005; White, Rayner, & Liversedge, 2005). The other parallelization disengages saccade preparation from saccade target selection. In SWIFT, the preparation of a saccade happens at the end of $L1$ but the target of the saccade is probabilistically determined at the time of saccade execution, based on word activation levels. Fixation duration is largely determined by a random process, but is also under the stochastic influence of the foveal processing (“foveal inhibition”). Overall, SWIFT allows the highest degree of parallelization among current models, based – implicitly or explicitly – on the notion of words.

² $L1$ was originally called the “Familiarity Check (fc) stage” in Reichle et al. (1998) and $L2$ the “Lexical Completion” stage. They have been referred to as simply $L1$ and $L2$ since Reichle et al. (2003).

The Strategy-tactics theory (O'Regan, 1990; Reilly & O'Regan, 1998) also relies heavily on words. The main feature of the model is the division between inter-word saccades and intra-word saccades. The former targets word centers (McConkie et al., 1988) whereas the latter are refixations that try to compensate for eccentric landing locations. Further reading efficiency is achieved by strategically selecting inter-word saccade targets, e.g., skipping short words and/or fixating long words (Reilly & O'Regan, 1998).

The "ideal observer" approach focuses on the identification of constraints of the problem space and search for optimal solutions. In this tradition, the challenge of eye movement programming is often recast as how to determine the optimal saccade target position in order to maximize the efficiency of lexical identification. Mr. Chips, a model which aspires to account for reading with retinal defects (Legge, et al., 1997; Legge, Hooven, Klitz, Mansfield, & Tjan, 2002), meticulously calculates the landing position in order to minimize the ambiguity in word recognition. Similarly, the recent *Split-fovea* model (Shillcock, et al., 2000; McDonald, Carpenter, & Shillcock, 2005) also focuses on optimizing landing position to ensure equal distribution of lexical information between the two hemispheres. The suggestion from these ideal observer models is clear: pre-position the landing location of the next fixation to facilitate foveal word recognition. In the presence of oculomotor noise, this optimal theoretical solution can be well approximated by the heuristics of always targeting word centers (Legge et al., 1997).

Troubles with spaces. Every aforementioned model requires texts to be pre-segmented into words. Removing spaces will disrupt saccade programming, slow down word recognition (and perhaps disable parafoveal previewing), and greatly increase ambiguities in sentence processing. Reading will be disorganized and deficient, if not downright impossible, according to these models.

There are, however, writing systems that do not visually mark word boundaries in any way. Chinese, Japanese, and Thai are contemporary examples. And until the 12th century or so Latin,

Greek, and other European languages were typically written unsegmented. Together, these comprise most of the human written history and a large portion of readers in the world today.

From the perspective of a word-based theory, the lack of word marking presents a challenge because the perceptual unit (letters, characters, or other glyphs) that serves as the basis for saccade programming is disconnected from the unit of language processing, i.e., words. In other words, oculomotor and linguistic processes run on different tracks, complicating the coordination of reading sub-processes. Some difficult choices have to be made in adapting a word-based theory to unsegmented orthographies. Saccade programming could be based on perceptual units (e.g., Yang & McConkie, 1994), but this would lead to random landing position and thus impede word recognition. Alternatively, one could salvage the word-based hypothesis by assuming that word segmentation occurs inconspicuously in the parafovea. This, however, is a potentially risky assumption. Word parsing in Chinese is notoriously difficult even for linguists (e.g., Duanmu, 1998). It is unlikely that Chinese readers can accomplish this linguistic feat, with only limited preview of upcoming characters, without adding time to the fixation duration. Either way, suboptimal reading performance is predicted for reading unsegmented scripts. This contradicts empirical observations that skilled readers of Chinese and English show remarkable similarities and few differences in eye movement parameters (see Feng, 2006 for a summary).

A potential solution is proposed by Tsai (2002), who suggested instead of identifying the “true” word (in the linguistic sense), saccade planning could be based on a proxy of words. Tsai specifically recommended a statistics based on the co-occurrence of characters, but presumably other shortcuts can work as well to drastically reduce the overhead of word parsing in real time. It is also tempting to justify the current word-centric approach by saying that orthographic words are a proxy to linguistic words.

Although this may appear to be an issue of modeling technique, I argue it represents a significant breach from the word-based tradition. It effectively rejects the often unstated axiom that oculomotor programming is based on the linguistic unit *word*. Instead, it replaces it with a

much softer assumption that saccade planning is based on perceptual units (e.g., Chinese characters) in a way that is linked to linguistic processing. The divorce between oculomotor planning and linguistic processes has far reaching consequences. Regarding reading unspaced scripts, it directs research attention to the statistical information in the orthography and connects different processes in reading. Furthermore, it raises questions about the status of the word in reading spaced orthographies such as English. What is a word? Is it conceptually necessary for a theory of reading? Or perhaps it is a marriage of convenience between the oculomotor and linguistic processes?

The Illusion of Words

What is special about the *word* that makes it the preferred unit of analysis in eye movement modeling? The justification – at least to English speakers – seems straightforward: Words are the fundamental linguistic unit and, as it happens, they are conveniently individualized in print. This, however, may be a happy linguistic coincidence. In the context of reading, words are not necessarily the most basic, natural, or critical level of linguistic processing. In fact, they are nothing more than what are flanked between spaces.

The elusive word. Despite strong intuitions of (literary) speakers, the *word* is notoriously hard to define in linguistics (e.g., Coulmas, 2003; Spencer, 1991; Crystal, 1997). A number of criteria have been proposed. For example, an influential definition by the prominent American linguist Leonard Bloomfield referred to *minimal free forms*, i.e., the smallest units of speech that can meaningfully stand on their own. Nonetheless, this leaves out functional words, such as English *the* and *to* or French *de*, which are conventionally written as words but can never stand alone in speech. The criterion of *indivisibility* – that no extra words may be inserted within a word – is intuitive, but it leads to the awkward conclusion that “*kick the bucket*” is a word but “*fantastic*” is not, because Robin Williams once exclaimed “*fan-bloody-tastic*” in the movie *Mrs. Doubtfire*. Individually or together, these criteria do not amount to an accurate, coherent definition

of *word* that applies to all human languages and all levels of linguistic analyses (Spencer, 1991; Coulmas, 2003).

A practical solution is to define *word* within each domain of study. For example, *phonological words* can be identified by stress patterns in English or by vowel harmony in Finnish. *Lexical words*, also called the *lemmata* or *citation forms* (as in dictionary entries), often come to mind as the prototype of words. But what goes into a dictionary is conventional and language-dependent. English happens to allow uninflected root morphemes (e.g., verb infinitives or singular nouns) to stand freely. Latin dictionaries customarily list the first-person singular present tense form of verbs. Modern Arabic, which has no infinitives, uses the third-person singular of the past tense as the citation form of verbs.

The *orthographic word* is arguably the closest to the notion of *word* in reading theories. Orthographic words are “the unit bounded by spaces in the written language” (Crystal, 1997, p. 420), although there are many other conventions to demarcate words (e.g., in Devanagari, letters are grouped by a horizontal head stroke that breaks at word boundaries; Daniel & Bright, 1996). Notions such as “word center,” “landing position,” and “word length” in the reading literature are clearly based on orthographic words.

Words identified at different levels of linguistic analyses do not necessarily correspond to one another. Some orthographic words (e.g., *a*, *of* and *to*) do not qualify as phonological words. Likewise, phrasal verbs such as “*put up with*” or “*take advantage of*” are effectively units of semantic analyses but are nonetheless orthographically divided. The distinction between compound words and phrases has always been subtle in English, and now instant messaging has made the fine line between *chat-room* and *bathroom* even thinner. Finally, the linguistic notion of *words* may not be universal. Yuen Ren Chao, the prominent Chinese linguist, concluded, “Not every language has a kind of unit which behaves in most (not to speak all) respects as does the unit

⁴ E.g., the suffix “-s” in *walks* represents PRESENT-TENSE, THIRD-PERSON, and SINGULAR at the same time.

called ‘word’ . . . It is therefore a matter of fiat and not a question of fact whether to apply the word ‘word’ to a type of subunit in the Chinese sentence (1968, p. 136).”

Words are composed of morphemes, the smallest meaningful unit of a language. Words often take on various *grammatical forms* when used in a sentence, and inflections and other morphological changes can dramatically transform the root word. Languages vary greatly in the degree of morphological complexity. At one extreme, *isolating* languages such as Chinese and Vietnamese make little use of inflectional or derivational morphology (e.g., no prefixes or suffixes); *words* are either bare root morphemes or simple compounds of them. At the other end, the entire sentence in a *polysynthetic* language may simply be an inflection of the root morpheme. English has a fairly impoverished inflection system (Booij, 2005; Crystal, 1997). English inflectional morphology is a largely *fusional*, where a single morpheme simultaneously represents a number of morphosyntactic properties.⁴ In contrast, *agglutinative* languages such as Turkish and Finnish tend to attach numerous suffixes, each with their own meanings, to the root morpheme (Crystal, 1997; Niemi, Laine, & Tuominen, 1995). This results in a larger number of morphemes per word and thus a longer word on average. It is estimated that Turkish, a language closely related to Finnish, has four times more morphemes per word than English has (Johanson, & Csató, 1998).

Implications for reading. No linguistic theory is based on orthographic words. The argument that (orthographic) words are the basic unit of linguistic processing has at least two problems.

Even in English, orthographic words do not correspond to the basic elements in syntactic or semantic analysis. The English-style word marking provides only limited help to the syntactic parser because it does not signal phrasal boundaries at all. In fact, the English orthography disrespects the syntactic boundary between phrases and compound words and frequently breaks compound words into morphemic components (e.g., the *White House*, rather than * *the Whitehouse*). On the other hand, English orthographic words are hardly the basic semantic unit either. Although English words tend to be short, it does not mean they are morphologically simple,

thanks to its fusional inflection system. English rarely marks morpheme boundaries (e.g., no **cran-berry* or **dis-please-d*; Booij, 2005). This suggests that some words may have to be parsed into morphemes before they are recognized. While most models of visual word recognition (for reviews see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Seidenberg, 2005) do not include morphological analysis, psycholinguistic evidence for morphological analysis in word recognition is paramount (see Reichle & Perfetti, 2003). English readers' gaze duration on a compound word is a function of the frequency of the whole word as well as that of its morphological components (Andrews, Miller, & Rayner, 2004), suggesting a competition between direct access and morphological decomposition (Carramazza, Laudanna, & Romani, 1988; Reichle & Perfetti, 2003).

Across languages, differences in orthographic conventions may entail different processes. When presented with long compound words, Finnish readers' first fixation duration was influenced only by the frequency of the first morpheme but not the second constituent, indicating serial morphological processing in Finnish (Hyona, Bertram, & Pollatsek, 2004). Reflecting differences in morphology, English compound words in the Andrews et al. study were typically 8-10 letters, whereas the Finnish compound words in the Hyona et al. study were much longer, approximately 12-18 letters. While the majority of the English compounds received a single fixation, over 90% of the long Finnish compounds were refixated, often for multiple times. When shorter Finnish compound words were used (7-9 letters; Bertram & Hyona, 2003), Finnish readers switched to an English-like pattern. But given the prevalence of long, morphologically complex words in agglutinative languages, word-based models of eye movement control have to be outfitted with additional mechanisms to deal with within-word eye movement programming.

To summarize, the notion of *words* in reading refers to orthographic words. Orthographic words provide the natural targets for saccade programming by virtue of being separated by spaces.

Beyond this, however, they may or may not map onto any meaningful linguistic units, across languages or even within a language. They are, after all, defined by the convention of writing.

Paraorthographical Marking and Eye-movement Planning

The reader may object at this point: Orthographic words may be what are flanked between spaces, but isn't the case that where we put spaces is based on our linguistic intuitions about words? My answer is "no," at least not historically. There is little evidence that a clear sense of words -- not as a vague ideas but an operational concept -- predates the widespread practice of orthographic word segmentation. Moreover, evidence suggests the interesting possibility that our intuition about the word may be an unintended side-effect of the development of conventions to facilitate visual and oculomotor processing.

I will begin this section by turning the clock back 2,000 years. We need to broaden the scope of investigation to include punctuations, because the earliest segmental signs were not spaces. The first obstacle we encounter, though, is notational: Because there is no word for the union of spaces, punctuations, capitalization, and other symbols or conventions that visually parse texts, we need to invent one.

What is Paraorthography? Paraorthography, a neologism, refers to a set of graphic symbols and conventions of a writing system that does not directly transcribe linguistic information but exists to ensure faithful transmission of the written message. "Para-" is a Greek prefix meaning *alongside of* or *beyond*, and by extension *a role ancillary or subsidiary to a role with higher status*. "Orthography," also of Greek origin, literally means *correct writing*. Just like spoken language, which is aided by *paralinguistic* elements such as body language, pauses, and intonations; written languages exploit a rich set of visual symbols and conventions -- punctuations, spaces, capitalization and font variations, page layout, etc -- to ensure and enrich the communication. The prefix "*para-*" is accurate in both historical and functional senses:

Paraorthographic systems evolved alongside of writing, and their primary role in writing is to assist and complement the work of the primary orthographic symbols – letters and other glyphs.

While many contemporary definitions of orthography include punctuations and capitalization rules (e.g., Crystal, 1997), these elements receive only sporadic scholastic attention (but see Nunberg, Briscoe, & Huddleston, 2001) and are often left to the hands of prescriptive language pundits (Truss, 2004). The proposal here is to separate the domains of orthography – which concerns itself with transcribing linguistic messages – and paraorthography, the convention (and often an art) of parsing and annotating written messages.

A brief history. Elements of paraorthography are as old as writing itself. For example, a conventional direction of writing – essential for planning eye movements in reading – was present in the Cuneiform writing some 6,000 years ago. Indentation and letter size (*litterae notabiliores*, the big and often decorative initial letters of a chapter) were used by 2nd-century B.C. scribes to indicate the beginning of important discourse units such as chapters or paragraphs (Parkes, 2003, p. 10).

However, separation of linguistic elements within major divisions of texts (i.e., paragraphs or arguments) was rare in Latin until the 6th century C.E. Although words in 1st-century Latin monuments and manuscripts were sometimes separated by small points (the *interpunct*; see Parkes, 2003, p. 263), by the end of the 1st century the practice was replaced by the Greek style *scriptio continua*, i.e., writing without any indication of word boundaries or places for pauses. The likely motivation for *scriptio continua* was to present the reader with a neutral text free of interpretations by the scribe: Authoring at the time meant dictating to scribes, who would mechanically write down the sounds without processing (or even understanding) the message. Any markings on surviving manuscripts from this period were likely supplied by later readers rather than authors.

The lack of visual segmentation of the text took tolls on the reader as he read the text aloud – the standard practice then. When asked to read an unfamiliar text, the 2nd-century writer, Aulus Gellius, exclaimed, “How can I read what I do not understand? What I shall read will be confused

and not properly phrased” (Parkes, 2003, p. 11). The 4th-century grammarian Servius recorded one of the earliest cases of misparsing by his colleague because of the lack of word spacing: *collectam exilio pubem* (“a people gathered for exile”) was mistaken as *collectam ex Ilio pubem* (“a people gathered from Troy”) (Parkes, 2003, p. 11). Silent reading was a stunt, far from the norm (Saenger, 1997).

In the 2nd century, systematic punctuations were used chiefly by teachers to help pupils’ literacy acquisition. The marks, which would include today’s equivalent of spaces, commas, periods, hyphens, stress markers, paragraph markers, etc., were punctuated by the teacher or by students themselves, not authors. By the 5th century, the demand for pre-punctuated texts surged as literacy spread to individuals not familiar with classical literary traditions. The usefulness of punctuations became widely recognized. Conventions of punctuations had emerged by the 5th to the 6th century (Parkes, 2003, p. 13), although individual idiosyncrasy abounded.

Two significant changes occurred during this period. The first is a shift of the function of punctuations. The primary concern for readers before the 5th century was to find sensible places to pause and breathe. For example, large comma-like signs drawn at different heights were used to mark pauses of various lengths. As silent reading became prevalent and as the need for accurate interpretation of Christian Scriptures became paramount, authors began to consciously put in punctuations to guide readers. Punctuation marks now took on a new role as indicators of text structure. For example, the *diple*, a long vertical bar on the margin, was used in the 6th century to indicate direct quotations from the Bible (Parkes, 2003, p. 17).

Another important change is the introduction of spaces between “words,” a practice pioneered by Irish scribes at the end of the 7th century to compensate their lack of familiarity with Latin (Parkes, 2003, p. 23). Slowly this practice spread to Anglo-Saxons scribes, to France, and eventually to most European countries by around the 12th century (Saenger, 1997). Historically, spaces were not always word-bound, though. Saenger (1997, p. 32) documented “aerated scripts,” frequently used in the early Middle Ages, where spaces were sparsely used to segment long lines

into letter strings approximately 20 letters long. Sometimes minor spaces further divided the text into smaller blocks. The resulting units, though, often did not correspond to meaningful linguistic units or rhetorical pauses. The purpose of the aerated scripts was to assist saccade planning.

Saenger maintains that

While the reader of aerated script cannot identify a word by its Bouma shape [the outline] or regularly rely on parafoveal vision to glean preliminary information about word meaning, aeration helped the reader to reduce ocular regressions by providing points of reference for orientation of the eye movements within a line of text as the reader grouped letters to form syllables and words. ... Thus, aeration made it possible for the reader to begin the cultivation of cognitive skills that had not been exploited by either the ancient Greeks or Romans. [p. 33]

It appears highly unlikely that medieval readers had an acute sense of where word boundaries were but simply refrained themselves from applying that knowledge. The struggles spanning over a millennium to invent a text segment system support the alternative hypothesis, where readers of *scriptio continua* did not have a clear intuition of what words were, and the sense of words is a by-product of inserting spaces in texts.

The next defining moment in the evolution of paraorthography was the introduction of printing technologies, which began to standardize shapes and conventions of punctuation marks. This process lasted several centuries after the first moveable type print shops were set up in the late 15th and early 16th centuries (Parkes, 2003, p. 51). A number of other paraorthographic conventions were also established: capitalization of the sentence initial letter, use of line spaces and indentation to indicate paragraphs, use of italic and bold type faces for various marking purposes, etc.

The establishment of paraorthographic conventions has forever changed the reading habit. Paraorthography has become a hard addiction to break. “Lord Timothy” Dexter, the 19th century American eccentric, published his memoir *A Pickle for the Knowing Ones, or Plain Truths in a*

Homespun Dress with no punctuations (and plenty of idiosyncratic spelling). In response to the publisher's demands for punctuations, he offered a full page of them in his 2nd edition, along with a note:

fouder mister printer the Nowing ones complane of my book the fust edition had no stops I put in A Nuf here and thay may peper and solt it as they plese [Dexter, 1838/2004, p. 36]

Paraorthographic variations. There are important cross-linguistic differences in paraorthographic conventions. Even within European languages, systematic differences in paraorthography abound. For example, English uses commas to bracket relative clauses, but only for the unrestricted type; in German all relative clauses require commas. German also keeps the tradition to capitalize all major nouns, a practice once popular in English publications but that has been replaced by the current style of only capitalizing sentence initial and proper nouns. The rules for spaces also differ from language to language. English uses spaces liberally, often dividing compound nouns such as “high school” as if they were phrases. Formal distinctions between compounds and phrases, e.g., the stress differences between “blackbird” and “black bird”, escape most native speakers. German, on the other hand, keeps all noun-noun compounds spelled together. Recent spelling reforms attempt to separate other types of compound words, but the reforms are under heated debate and the fate of German compounds is remains to be seen (Johnson, 2005).

While most writing systems today use spaces to some extent, the linguistic units they mark can be quite different. Spaces often mark linguistic units smaller than words. Written Chinese clearly demarcates individual characters, which are always monosyllabic and usually correspond to a single morpheme; words, in the phonological or grammatical sense, are not marked in any way in writing. Japanese, under the influence of Classic Chinese, also leaves no extra spaces between words; its Kana and Kanji characters represent different linguistic units. Kanji (Chinese) characters typically correspond to lexical and phonological words, whereas the kana's correspond to syllables (or *mora*'s; Coulmas, 2003). Derived from Devanagari, Thai is a well-known

non-spaced, alphabetic orthography. The Thai language is a tonal, uninflected, and predominantly monosyllabic language (Coulmas, 2003). There are polysyllabic loan words, but word boundaries are not indicated with additional spaces. Thai does not use Western punctuations; in fact, it rarely uses any punctuation at all, other than the extra space at the end of a sentence. The Korean Hanguk is an alphabetic writing system that also features syllables as visual units. It differs from the above languages in that it puts additional spaces between words, a recent adaptation from the West (Sohn, 2001).

Functions of paraorthographic marking. The oldest function of punctuation goes back to its origin two millennia ago, i.e., as transcription of paralinguistic features such as pauses, intonation, stress, etc. (Crystal, 1997; Lawler, 2006). The Spanish inverted question mark (¿) alerts the reader of an upcoming question, because a statement may be syntactically indistinguishable from a question except for the intonation. A subtle case in English is the comma, which often represents a *mid-low*^{*high*}-*mid* sequence (Lawler, 2006). Thus the use of commas in counting “fifty-one, fifty-two, fifty-three, ...” gives an “authorial voice.”

More relevant to reading eye movement planning are two relatively new functions of paraorthographic symbols. The first is to provide a hierarchical segmentation of a written text. It is evident from the evolution of punctuation that paraorthographic conventions distinguish four levels of linguistic objects: (a) paragraphs or major sections of texts, which are discourse level objects that were among the earliest to be marked; (b) sentences, or major pauses, are marked not only with periods (or “!” or “?”) but also with capitalization of the initial letter; (c) the clause and/or phrasal level, or minor pauses, often marked with comma; and (d) words, flanked by spaces and occasionally with hyphens. The paraorthographic system not only segments the text with a rich set of explicit markers but also visualizes the hierarchical structure. This is a great advantage over spoken language processing and should be something to be exploited in eye movement programming.

Another role of punctuations is to indicate status of a constituent, what Nunberg called the “text grammar,” a set of rules that determine syntactic relations among elements of written texts (Lawler, 2006; Nunberg, 1990; Nunberg, et al., 2001). For example, the following example (Nunberg, et al., 2001, p. 1736) is invalid because it requires a matching comma to the left of “in fact” in order to signal that the parenthetical phrase is not at the same level as the main sentence.

* *Jill was in fact, keeping her opinions open.*

By using punctuations and other paraorthographic conventions, the author embeds a series of visual clues in the text, with the intention of illuminating the hierarchical structure of the text and guiding readers through potential parsing hazards. No paralinguistic system in spoken language provides as much systematic scaffolding, despite the inherent idiosyncrasy and inconsistency in the everyday usage of paraorthographic symbols. This is necessitated by the nature of written communications – one-way, asynchronous, solitary, and without paralinguistic support. And history shows that its evolution was driven primarily by the readers. What are the paybacks to the readers, then?

Paraorthography and eye movements. Paraorthography is designed for eye movement guidance. This is a hypothesis entertained by medievalists Parkes (2003) and Saenger (1997). In addition to the historical evidence they have amassed, some eye movement data also support the conjecture.

First, there is a history of extraordinary difficulties in parsing unsegmented text into meaningful linguistic units, words or otherwise. Whatever eye-movement strategies *scriptio continua* required, it could not have been efficient for word recognition. There are a handful of studies on reading English without spaces. Epelboim and colleagues (Epelboim, Booth, & Steinman, 1994; see also Epelboim, Booth, Ashkenazy, Taleghani, & Steinman, 1997) found that native and second language readers of English can read *scriptio continua* (albeit with punctuations), but at the cost of about a 30% reduction of reading speed. Rayner and colleagues estimated an approximately 50% decrease in reading rate (Morris, Rayner, & Pollatsek, 1990;

Rayner et al., 1996; Pollatsek & Rayner, 1982). While readers are able to comprehend unspaced text fairly well, just like readers 2,000 years ago, their reading efficiency suffers.

Second, paraorthography is designed to group orthographic symbols linguistically as well as visually. Indeed, what could visually segment a letter string better than blank spaces, or blank spaces with minuscule dots? Were it just for linguistic segmentation, less visually salient symbols would suffice. Spaces around words reduce lateral inhibition at word borders and therefore make the initial and final letters much more perceivable. Johnson, Perea, and Rayner (2007) showed that extreme letters contribute more to the parafoveal preview benefits than word-medial letters. Most importantly, the orthographic images of words now stand out as individual visual objects, allowing them to be recognized as perceptual wholes rather than a collection of letters. Its significance can only be appreciated when one considers how reading was done before this point. Saenger (1997, p.85) wrote that “word separation ... provided shortcuts for achieving the reading skills that an elite among the ancients had mastered only through a prolonged and arduous grammatical apprenticeship.”

The final observation, perhaps more of a conjecture, is that segmental punctuation marks are evolved to guide parafoveal saccade programming. Evidence comes from historical changes in the shapes of many punctuation marks and word delimiters: The general trend is a reduction in their spatial frequency, either through simplifying strokes or by widening the symbols. In other words, punctuation becomes more like blank space. Until 11th century letter *h* and the diacritic *dasia*, silent letters in Medieval Latin were sometimes used as word separators (Saenger, 1997, p. 84). The Irish scribes used a ‘7’-like sign for pauses, and the letter **K** (for *kaput*, or ‘head’ in the argument) was used to introduce a new *periodus* (Parkes, 2003, p. 12). Eventually all these symbols were replaced by ones visually distinctive from letters. This would be a welcome change for the oculomotor system. Punctuated texts appear in the peripheral as separated objects of variable lengths. Our oculomotor system knows how to deal with this kind of visual input (Findlay & Walker, 1999).

The evolution of paraorthography was a history of pluralism and idiosyncrasy. But what emerged from the chaos was a set of symbols and conventions that segment texts linguistically as well as visually. Compare our reading experience with Quintilian's description in the 1st century: Reading requires "dividing the attention so that the eyes are occupied in one way and the voice another" (*dividenda intentio animi ut aliud voce aliud oculis agatur*; Parkes, 2003, p. 10). The co-evolution between eye movement planning and the paraorthographic system has played an important role in changing the nature of reading.

The Paraorthographic Linkage Hypothesis

The chapter began by examining a common assumption among current theories of reading eye movements, i.e., the concept of *words* links visual word identification, post-lexical linguistic processes, and saccade planning together as an optimal system. I argued the *word* is not a unit of linguistic analysis but a result of writing conventions. The last section took a historical look of the emergence of paraorthographic conventions and suggested that paraorthography was developed, at least in part, to ease all three aspects of reading. We now come to the natural conclusion: Paraorthographic symbols, not *words*, enable optimal coordination of sub-processes in reading.

Unlike the word, which is presumably a unit of language, paraorthographic symbols result from intentional human actions. They are the breadcrumbs⁶ the author left to lead the readers to the correct interpretation of the message. Paraorthography also provides optimal (or near optimal) solutions to the time-compression challenge in reading, by virtue of trial-and-error over millennia. By this account, the reason word-based theories enjoy extraordinary success in English reading is because they capture the essence of what the English paraorthographic system set out to do. By the same token, a key to understanding eye movement control in a different language is to know what paraorthographic aids readers and writers of the language have already established.

⁶ In **the** Brothers Grimm fairytale *Hansel and Gretel*, the two boys left breadcrumbs along the trail in order to find home.

The Paraorthographic Linkage Hypothesis (PoLH) attempts to formalize these insights. It starts with the assumption that at the initial stage the three main components of reading – foveal and parafoveal object (word) identification, language comprehension, and saccade planning – are independent and not well coordinated. Their coordination will improve with reading experience, but optimality is often achieved with the guidance of the paraorthography. Specifically, PoLH involves three principles:

Loose coupling. A basic premise of the PoLH is that saccade planning, visual recognition, and language comprehension are three separate modules prior to the emergence of reading and writing. They are loosely connected in the initial stage. In other words, proficient reading processes originate from a set of ineffective, poorly coordinated sub-systems.

The disassociation among the three sub-systems is self-evident. We move our eyes when we are not reading. Our linguistic faculty also exists before we can read or write. Foveal processing can also be divorced from saccade planning. Word recognition can be accomplished without moving the eyes. In fact, classic RSVP (Rapid Serial Visual Presentation) studies have shown that reading speed can be temporarily raised to 1200 words per minute if words are flashed in succession at the fovea (Juola, Ward, & McNamara, 1982, but see Masson, 1983, on effects on comprehension). Conversely, we also appear to have no trouble making reading-like eye movements without any linguistic processing. A number of studies asked readers to “read” nonsense letter strings that resemble print, i.e., with comparable paraorthographic marking such as paragraphs, punctuations, and “word” spaces (Vitu, O’Regan, Inhoff, & Topolski, 1995). At the surface level eye movements in scanning nonsense strings share some important similarities with those in reading.

A reasonable but obviously ineffective strategy, one that may be initially adopted by beginning readers, is to plan the next saccade only after foveal word recognition is completed. This would leave approximately 100 milliseconds per fixation in idle while waiting for oculomotor

programming and execution. Improvement over this strategy relies on two additional factors – our intrinsic capacity to learn and optimize and the paraorthographic clues authors left.

Paraorthographic Linkage. Spaces, punctuations, capitalizations, and the like are the breadcrumbs that lead to the message intended by the author. Paraorthography not only prevents readers from wandering astray but also enables seamless integration of the sub-processes. This hypothesis follows from the functions of paraorthographic symbols – they visually parse written symbols into meaningful linguistic units, and they signal syntactic and semantic relations among linguistic entities.

The disambiguating function of interword spaces has been discussed in the previous section. Much less discussed in the eye-movement literature is the role of paraorthography in signaling relations among linguistic constituents (Nunberg, 1990). As the current sentence shows, even with words clearly identifiable note this gives the reader a huge advantage over first century monks comprehension is still impaired to a point of pain. The use of punctuation releases us from constant struggles with syntactic ambiguities during reading. Ironically, the ubiquity of punctuation in today’s texts gives rise to models of reading eye movements that ignore their presence.

Spaces or other word separators reduce the difficulty of foveal processing in a number of ways. First, having spaces eliminates the need for parsing letter strings into linguistic units for recognition. Furthermore, the initial and final letters of a word are more salient and identifiable with spaces. Last, paraorthographic symbols enable consistent representations of individual orthographic words, as opposed to words embedded in unpredictable letter sequences. This should amplify perceptual learning during repeated print exposure and further speed up foveal – and potentially parafoveal – word recognition. Similarly, parafoveal processing also benefits from paraorthography. The most well-known factor is use of the length of the upcoming word in guiding saccade programming during English reading (see Rayner 1998). In addition, by reducing lateral

inhibition, spaces also allow at least partial identification of the extreme letters of parafoveal words (Johnson et al., 2007).

Compared to *scriptio continua*, separated and punctuated texts afford more efficient reading strategies (McConkie et al., 1988): Programming the eye to go to the OVP of a parafoveal word, which minimizes foveal processing time, leaves more time for parafoveal processing; this in turn allows more judicious choice of the next saccade target. In addition, with most of the potential syntactic and discourse parsing ambiguities taken care of by punctuation, foveal word identification becomes the primary constraint in eye movement programming. This confirms one of the assumptions of current eye movement models.

The optimal strategy for reading English may not necessarily be adaptive for reading other languages. When orthographic words are long and morphologically complex, multiple fixations may be required for word identification. It would not be advisable to target the center of a long word in the parafovea; instead, shooting for somewhere left of the center is more likely to provide the morphological parser with useful information.

The optimal reading strategy is neither hardwired nor explicitly taught. The only way to achieve efficiency is through unsupervised learning from experiences. And reading provides a plethora of opportunities to do so.

Optimality. The third principle is concerned with the acquisition of proficient reading strategies. An optimal strategy is defined here as one that maximizes system performances in the long haul. One way to characterize reading performance is the speed of reading at a certain level of comprehension (Carver, 1990). In other words, the goal of optimization is to achieve the most efficient reading while maintaining comprehension. A computational model of the optimization process will be presented elsewhere (Feng, 2007). Here I will focus on evidence for the optimization process and the facilitative role of paraorthography.

Evidence of developmental changes in reading is overwhelming. By 5th grade, an avid reader is exposed to over 4 million words per year, and even the average 5th grader reads over a

half million words each year (Anderson, Wilson, & Fielding, 1988). The sheer amount of practice dwarfs any other complex cognitive skills that are not part of our biological endowment. The impact of these exercises is profound. From first grade to college, children's reading speed increases more than threefold, from approximately 80 wpm to 300 wpm (Taylor, 1965; Carver, 1990). The average fixation duration decreases over time and saccade length increases, along with other changes toward a more adult-like pattern (see Rayner, 1998). Children's ability to consciously control saccade programming also improves with age (Fischer, Biscaldi, & Gezeck, 1997).

Paraorthography contributes to the optimization of reading processes in two ways. New paraorthographic conventions changed the nature of the text and the task of reading. In addition to these "hard" changes in the text and processing, paraorthography also introduced more subtle or "soft" cues that are no less important. Specifically, spaces and punctuations allow readers to further improve reading performance based on probabilistic regularities that were not available before.

For example, additional time could be saved if the foveal word recognition time were known before hand. In this case the timing of oculomotor planning would be adjusted to minimize the "idle" time, i.e., the time between the completion of foveal word processing and the initiation of the next saccade. Such information can potentially be calculated by a learning algorithm. With a sample size in the millions, the estimates are potentially very informative for eye movement programming.

Clearly, these statistics are unimaginable in *scriptio continua*. Foveal processing would be preoccupied by lexical parsing and other processes. Parafoveal information such as word length was also unattainable. First century Latin readers must have optimized their reading processes in some ways, but the range of information provided by the paraorthography was extremely impoverished by today's standard. This reiterates the point that the reading process, as we know it, down to the split-second decisions readers make, is ultimately the creation of the paraorthographic

system. Understanding the co-evolution of the two may shed new light on current debates in the literature.

Conclusions

At the onset of the chapter I contrasted the *trinity of the word* with a view that rejects the notion of the word as the conceptual basis for reading eye movement control. I argued that words – more precisely the orthographic words – bear no direct relationship with levels of linguistic analyses. As the foundation of a theory of reading eye movements, the concept of the word is convenient, intuitive, but ultimately illusive.

As an alternative, the Paraorthographic Linkage Hypothesis (PoLH) argues that, historically and cross-linguistically, reading processes are strongly constrained by paraorthography, which are the metaphorical breadcrumbs helping readers to reach intended interpretation of the author's message. To the extent paraorthography differs across language, the optimal reading processes should also differ accordingly.

The proposal here, however, is not one of linguistic relativism (e.g., Hoosain, 1991). Quite the contrary: The moral of the story is that readers constantly adapt and optimize their reading behaviors. It is this ability to adapt and to optimize that forms the basis for the universal theory of reading, not any of its end products.

Lastly, the PoLH has direct implications for reading Chinese, Japanese, and other non-spaced languages. From the point of view of current eye movement models, which are almost invariantly word-based, eye movement programming in these orthographies is paradoxical: how do you move the eyes to the next word if you don't know where the word is? The advice from PoLH is: Forget words, look for other cues. According to the PoLH, proficient readers in these languages are well-adapted to their own writing systems. Thus the paradox has always been in the researcher's mind, never the reader's. The starting point of an eye movement model for a new language should be to investigate constraints of the language and writing system, with the

assurance that readers will always find the best solution, provided that they, well, read.

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