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Universality in eye movements and reading: A trilingual investigation

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ABSTRACT

Universality in language has been a core issue in the fields of linguistics and psycholinguistics for many years (e.g., Chomsky, 1965). Recently, Frost (2012) has argued that establishing universals of process is critical to the development of meaningful, theoretically motivated, cross-linguistic models of reading. In contrast, other researchers argue that there is no such thing as universals of reading (e.g., Coltheart & Crain, 2012). Reading is a complex, visually mediated psychological process, and eye movements are the behavioural means by which we encode the visual information required for linguistic processing. To investigate universality of representation and process across languages we examined eye movement behaviour during reading of very comparable stimuli in three languages, Chinese, English and Finnish. These languages differ in numerous respects (character based vs. alphabetic, visual density, informational density, word spacing, orthographic depth, agglutination, etc.). We used linear mixed modelling techniques to identify variables that captured common variance across languages. Despite fundamental visual and linguistic differences in the orthographies, statistical models of reading behaviour were strikingly similar in a number of respects, and thus, we argue that their composition might reflect universality of representation and process in reading.

1. Introduction

The issue of universality has been central to linguistics and psycholinguistics for decades. Chomsky (1965) argued that "...the main task of linguistic theory must be to develop an account of linguistic universals that, on the one hand, will not be falsified by the actual diversity of languages, and, on the other, will be sufficiently rich and explicit to account for the rapidity and uniformity of language learning, and the remarkable complexity and range of the generative grammars that are the product of language learning" (pp. 27–28). In a recent article, Frost (2012) makes a strong argument for a Universality Constraint in relation to reading, suggesting that psychological models of the process of reading should reflect cognitive operations that are common across languages with different writing systems or scripts. In his thesis, Frost goes beyond the traditional Chomskyan notions of universality, making the case for cross-linguistic commonality at the level of cognitive processing. Frost further argues that establishing reading universals is a prerequisite for the development of meaningful, theoretically motivated cross-linguistic models of reading. The responses to Frost's target article are very interesting in that they reveal a broad spectrum of views pertaining to the issue of universality in relation to written language processing, ranging from broad agreement (e.g., Feldman & Moscoso del Prado Martin, 2012) through to the suggestion that there are no such things as universals of reading (Coltheart & Crain, 2012). The views delivered in the article along with the responses to them provide a very relevant context to the experimental project that we report here. We were keen to investigate whether it might be possible to identify factors that could account for common variance across very different written languages in an on-line measure known to reflect moment-to-moment cognitive processing during reading. Our objective in doing this was to first establish whether such variables did exist, and if so, try to evaluate whether those variables might represent universal aspects of reading. If such universals do exist, they represent common principles by which the written language processing system extracts information from print across different languages. Indeed, if this is the case, then one of the strongest predictions that can be made on the basis of Frost's universality formulation is that whilst different writing systems may visually represent linguistic information in quite different ways, the extraction of meaning from comparable units of language should require

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a similar amount of time. That is, whilst the moment-to-moment machinations of meaning computation may differ across languages, overall, the time to compute meaning from comparable units of written language should be similar. Arguably, at a fundamental level, universality suggests that an assumption of temporal unity in relation to the attainment of comprehension (regardless of visual format) should hold, and this in turn strongly implies comparability in the time required to attain that state. Finally, our approach in this project also provided an opportunity to pursue a more general objective, namely, to provide comparable cross-linguistic descriptives of reading behaviour.

Before developing our claims in detail, it is necessary to be clear about two points. First, unlike the implicit position adopted by Frost (2012), we do not consider theories of written word identification to be the equivalent of theories of reading (see Liversedge, Blythe, & Drieghe, 2012). Instead, we consider comprehension of multi-word text to constitute reading, rather than simply the identification of isolated words. Furthermore, it is our view that word identification occurs differently for isolated words than during normal reading (see Rayner & Liversedge, 2011). Thus, whilst word identification is clearly a central and critical aspect of reading, numerous other cognitive processes are also required for successful text comprehension (e.g., syntactic, semantic, discourse processes, anaphor resolution, inferential processing, etc.). For these reasons, when we discuss reading in the present article we include consideration of processing beyond word identification. Our second qualification concerns exactly what we mean when we refer to universality. As should become clear, we do not restrict our use of the term to the notion of Formal and Substantive Universals as originally stipulated by Chomsky (1965). Instead, perhaps unsurprisingly, we will consider universality in relation to representations and cognitive processes that are common to reading across languages (with the exception of Braille). It is in this sense that our claims will be about aspects of written language processing that are universal.

As mentioned, reading is a visually mediated psychological process. Humans process visual information via the eyes. Visual information, and more specifically in the case of reading, text, is encoded and then represented in an abstract form after which it is linguistically processed by later cognitive systems. Written language comprehension results in the formation of a representation of the meaning of text, often referred to as a discourse representation. In this sense, the human visual processing system (including "the brain's letter-box", Dehaene, 2009) sub-serves the linguistic processing system, delivering the information that the language processor needs in order to carry out its computations. As already indicated, the eyes are the means by which visual information is encoded for subsequent processing, and the human eye has a particular physiological make up that has important implications for the eyes' functional role in the uptake of visual linguistic information. At (approximately) the middle of the retina there is the fovea, a small circular area (roughly 2°), that provides high acuity visual information, and beyond which, in the parafovea and the periphery, vision is of much reduced visual acuity. Consequently, this causes humans to visually sample their environment by making a series of fixations, which are short periods where the eye is comparatively still (usually lasting about quarter of a second during reading), and saccades, which are fast, ballistic rotations of the eyeball. During fixations humans cognitively process the visual information that they have encoded, whereas during saccades, there is no useful visual input. All humans across all cultures who have an undisrupted visual system visually sample their environment in this way (Findlay & Gilchrist, 2003), and it has been argued that saccadic sampling has evolved due to its efficiency in relation to visual information processing (Gilchrist, Brown, & Findlay, 1997). Furthermore, eye movements are very largely under cognitive control, and measurement of temporal and spatial properties of saccades and fixations during reading provides an excellent online index of cognitive processing (Liversedge & Findlay, 2000; Rayner, 1998, 2009). Thus, despite our perceptual experience during reading being one of a smooth, continuous flow of information, in fact, it takes place via a staccato succession of discrete snapshots, each providing detailed information from a small portion of the sentence (usually a word or two). In other words, detailed visual information necessary for linguistic processing beyond the centrally fixated (foveal) region is not available. It is important to understand, however, that readers do not exclusively process text directly at fixation. If this were the case, then linguistic processing would be extremely tightly yoked to specific fixations (c.f., the Eye-Mind Assumption, Just & Carpenter, 1980). Instead, there has been substantial work (see Rayner, 1998, 2009) showing that readers partially pre-process upcoming text in the parafovea in the direction of reading (McConkie & Rayner, 1975; Rayner, 1975). In sum, saccadic eye movements during reading are common throughout the human species, regardless of culture or language, and saccadic sampling and the retinal make-up constrain the rate at which visual information is encoded and delivered by the visual system to the language processing system.

Not only does commonality exist in relation to human eye movements during reading, but also certain linguistic effects on eye movement behaviour occur across languages. For example, lexical frequency effects are known to occur robustly across most languages such that words that are more frequent are read more quickly than words that are less frequent (Ellis, 2002). Also, word length effects have been demonstrated across languages, whereby longer words take longer to read than shorter words (Bertram & Hyönä, 2003; Just & Carpenter, 1980; Rayner, Sereno, & Raney, 1996). Finally, words that are more predictable on the basis of preceding sentential context are read more quickly than words that are less predictable (Balota, Pollatsek, & Rayner, 1985; Ehrlich & Rayner, 1981; Inhoff, 1984). The fact that word frequency, word length and word predictability effects (the "big three" in reading, Clifton et al., in press), are found across languages provides evidence for the more general suggestion of the importance of word based processing during reading across languages (see Li, Bicknell, Liu, Wei, & Rayner, 2014).

The next point that we will consider concerns the script, or the physical form of a written language. As Perfetti and Harris (2013) make clear, reading depends on the writing system that encodes the language. We strongly concur with this view. Here, we will consider the writing system of the language in relation to two issues relevant to reading: (1) the visual and informational density of the written language and (2) the intricacies of the orthography (notational system) that capture and represent linguistic characteristics.

Scripts vary across languages to a very significant degree. Some written languages are extremely, visually dense (e.g., Chinese), whilst others are less dense and (usually) horizontally spatially extended (e.g., English, or even more so, Finnish). To be clear, by visual density, we mean the amount of visual information that is available per unit of text. This definition, in itself, raises complexities in relation to what actually constitutes a unit of text. For the moment, however, let us sidestep this question and consider visual density in relation to one of the three languages we have chosen to examine. In written Chinese, visual density can be indexed in terms of the stroke complexity of characters and words (e.g., Liversedge et al., 2014) since all characters occupy the same unit of space, and some characters are comprised of many strokes, whilst others are comprised of comparatively few; the more strokes that comprise a character or word, the greater the visual density. Note, though, that not all strokes carry equivalent weight within a character (Wang et al., 2013; Yan et al., 2012), and for this