Vision Research 48 (2008) 2309–2320

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

The consequences of violations to reading order: An eye movement analysis ☆

Alan Kennedy [a,b,*], Joël Pynte [b]

[a] School of Psychology, The University of Dundee, Scrymgeour Building, Tayside, Dundee DD1 4HN, UK
[b] Laboratoire de Psychologie et Neurosciences Cognitives, Boulogne-Billancourt, France

ARTICLE INFO

Article history:
Received 12 November 2007
Received in revised form 9 July 2008

Keywords:
Reading
Eye movement control
Sequential reading order
Noun–Adjective order

ABSTRACT

Adjective–Noun and Noun–Adjective sequences inspected with single fixations in the French part of the Dundee Corpus were examined. Violations to canonical reading order produced significant effects on average inspection time, but only for fixations on the two words concerned and the immediately following fixation. Extended analyses on both English and French data sets also show local consequences of violations to reading order, but only very limited evidence of longer-lasting effects on wrap-up. The fact that a failure to maintain a strict left–right serial reading order seems not to result in significant processing disruption poses a challenge to current models of eye movement control in reading.

1. Introduction

This paper is concerned with the possible consequences of inspecting words in text in a temporal order that violates their spatially defined word order (i.e. the disposition of the words on the screen or printed page). Eye movements in reading are generally quite systematic with respect both to their timing and their location (Rayner, 1998) and there is, in fact, a largely implicit assumption that normal reading by proficient adult readers[1] involves the orderly inspection of words in turn, where "in turn" is defined by spatial succession. The perceptual unit in text is assumed to be an orthographically defined "word object" (McConkie, 1979) and the reader's task to direct attention to each such object in turn. A clear example of such an assumption can be found in serial models of eye movement control, deriving from the work of Morrison (1984), of which the *E–Z Reader* model (Reichle, Pollatsek, Fisher, & Rayner, 1998) is the most successful recent example. A strict isomorphism between the (spatially defined) serial order of words in text and the order in which the lexical properties become available is a defining feature of models of this kind ("...a spatial attentional system that operates from left to right across the page will automatically reproduce the temporal order of the words in a spoken sequence of English", Pollatsek, Reichle, & Rayner, 2006, p. 9). Such models are properly described as "serial" in two senses: first, eye movements are under the direct and immediate control of lexical properties of a given word and, as a result, their deployment honours the serial order in which words occur. Second, with limited exceptions, lexical processing is seen as *discrete* rather than distributed, processing taking place on a "leave-on-completion" basis. In contrast, a number of models of eye movement control envisage a gradient of attention within which a degree of parallel processing can occur. The SWIFT model of Engbert, Nuthmann, Richter, and Kliegl (2005) is the best-known and most explicit model of this kind. Engbert et al. argue that the mechanisms governing "*where?*" and "*when?*" decisions in eye movement control operate on such different time lines that the notion of a single attentional spotlight switching from word to word seems implausible. In its place, they propose a field of activation undergoing a continual process of dynamic change. At any given time, several words may be competing to be the target of the next saccade. For theorists adhering to a parallel processing point of view, visual attention is seen as a distributed resource and not as a series of unique trigger events linked to eye movement control. Indeed, the initiation of a saccade is seen as an essentially random autonomous event, albeit capable of being delayed by processing demands. At the time of target selection, saccades are launched towards possible targets determined by the probability of their relative lexical activation (Luce's choice rule). A target may or may not be the spatially adjacent next word. In the case of the serial model, words are processed in the correct order because there is no alternative. However, distributed processing of the kind found in the SWIFT model implies parallel lexical activation and the problem of how the reader arrives at the correct word order becomes acute. As Reichle, Pollatsek, and Rayner (2006) point out, parallelism of this kind appears underspecified, because the presence of cross-talk involving rival lexical candidates conflicts with the primary goal of

☆ We are grateful for comments from Reinhold Kliegl, Keith Rayner and an anonymous reviewer. This research was supported by Grant No. R560.805823 from the UK Economic and Social Research Council.

* Corresponding author. Address: School of Psychology, The University of Dundee, Scrymgeour Building, Tayside, Dundee DD1 4HN, UK.
E-mail address: a.kennedy@dundee.ac.uk (A. Kennedy).

[1] It is well-known that this is not the case with beginning readers, although it is rarely made explicit whether reading difficulty should be seen as a cause or a consequence of this fact.

0042-6989/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2008.07.007

the reader, to produce a single unambiguous cognitive representation. Explaining how this is achieved in a truly parallel model is difficult. Engbert et al., for example, suggest the job of working out the correct serial order might be delegated to an autonomous module, but it is unclear how this is to be achieved while at the same time retaining the notion of parallel lexical activation (Kliegl, Nuthman, & Engbert, 2006; Rayner, Pollatsek, Drieghe, Slattery & Reichle, 2007).

Although the *E–Z Reader* and SWIFT models model have sharply contrasting architectures, each is challenged in a different way by the fact that a mapping between spatial and temporal word order has to be achieved. In the serial model, words must become available to the reader in the way they would if the text were spoken. Beyond those spatial discontinuities that the model can cope with (e.g. skips and certain classes of re-inspection), there is no problem of spatial order to be solved because reading should be *inherently* orderly. The difficulty with this claim is that it has been known at least since Buswell's early work (Buswell, 1920) that in oral reading the eyes are frequently ahead (sometimes far ahead) of the spoken word, but also sometimes lagging significantly behind. The pattern of eye movements in normal silent reading shows many similar departures from canonical reading order, in which the close coupling between the reader's eye position and the reader's attention is broken. Many such discontinuities are handled by the *E–Z Reader* model by setting parameters such that a non-canonical order of fixations, nonetheless, supports a canonical distribution of attention. But there must be a limit to this, at which point, as noted above, reading words in an order that violates the spatially defined left–right sequence should incur a penalty. It follows that two predictions can be derived from the serial model. First, the deployment of the reader's eye movements should be generally orderly: parafoveal pre-processing will license a number of discontinuities (in particular word skips), but beyond that, breaks in the canonical temporal–spatial coupling should not occur. Second, drawing on the comments of Pollatsek et al. (2006) cited above, if violations to canonical reading order do occur this will cause a major disruption to on-going processing and, at the limit, to comprehension difficulties.

Deriving predictions for a model involving parallel lexical activation is less straightforward. In this case, saccades are launched towards that target word that has the highest level of activation at the point of launch. It follows that deviations from the canonical spatial order may be ubiquitous. Nonetheless, the notion of distributed lexical activation, with many candidate words simultaneously competing for the next saccade, does appear to deprive the model of its primary function: that is, the extraction of a single coherent representation of meaning. There is a clear prediction that canonical reading order should be routinely violated, but, if such a prediction is supported, the challenge provided by simultaneous multiple representations of meaning may remain un-solved. As Pollatsek et al. put it, "...*run home* means something quite different from *home run* in the spoken language. As a result, if the reader, in trying to process these two adjacent words in parallel encodes them in an order other than going left to right, the utterance will be misinterpreted" (p. 39). The authors of SWIFT are not insensitive to this point and have, for example, discussed the advantages to be secured from the parallel perspective of a model employing some lower-level token like letter sequences (Engbert et al., 2005), but this has not been implemented and it is, in any case, rather unclear how it would solve the "multiple meaning" problem. Thus, for a parallel model the problem does not reside in a claim that reading must be essentially serial. The problem is how, if this is not true, a single representation of meaning is ever constructed (the *run home*, *home run* question).

The present paper addresses three questions: (1) assuming a definition of non-canonical or "disorderly" reading can be determined, how frequently does this occur in normal reading? (2) What are the local or immediate consequences, if any, of inspecting words in text in a non-canonical way? Is there, for example, a characteristic signature in the eye movement record equivalent to some of the disfluencies found in oral reading? (3) Assuming non-canonical reading occurs to some degree, does it incur a processing penalty? Analyses of the incidence of mis-matches between the temporal order of fixations and the spatial order of text have, up to the present, been restricted to attempts to count and classify particular "patterns of fixation" (e.g. Engbert, Kliegl, & Longtin, 2004; Hogaboam, 1983). Progress towards a more general quantitative analysis has been slow because arriving at a definition of "disorderly" reading is not straightforward. The present paper represents a first step towards providing such a definition, and then using it to address these three questions.

Consider the case of the first English participant reading the first sentence of the texts comprising the Dundee Corpus (Kennedy, 2003b). The sentence is: "*Are tourists enticed by these attractions threatening their very existence?*" The temporal sequence of fixations and other events in the first pass is as follows: "*Are tourists enticed these attractions attractions threatening BLINK threatening very their existence?*" The word "by" is skipped; the word "attractions" is examined twice; the word "threatened" is also examined twice, but with an 82 ms blink between "fixations". The two words "their" and "very" are examined in reverse order and it should be noted that even this very modest violation to normal spatio-temporal mapping involves a complex pattern of eye movements. That is, the word "their" is initially skipped (possibly because it has already been processed in parafoveal vision) but is, nonetheless, then examined (or "re-examined") after looking at the word "very", which is itself then skipped by a saccade that lands two words downstream. The text is not inspected at random and, by and large, word order is honoured, but clearly some violations to canonical reading order are present. In this case, they are relatively minor. As noted, skips may simply reflect successful covert (parafoveal) processing, and it could be argued that the attentional mechanism honours the correct underlying temporal order, even if the eyes do not. In which case some apparent irregularities may not represent "violations" at all. However, as deviations become more severe, it becomes increasingly difficult to accommodate them in this way. The logic of the procedure adopted in the present paper involves two steps. First we take a highly constrained example of non-canonical reading order, examining cases where Noun–Adjective and Adjective–Noun sequences in the French language were read in their correct or incorrect order. Second, we derive an index of orderly reading that excludes cases that might plausibly be accounted for by attentional pre-processing. The role played by non-canonical reading, indexed in this way, is then examined in the Dundee Corpus (English and French). Our purpose is to show the immediate and delayed effects of a non-canonical reading order, if any, on text processing. Interestingly, this is a paradigm case of a question not readily amenable to experimental investigation because attempts artificially to induce violations to reading order are likely to be counter-productive.[2] On the other hand, it is ready-made for *post-hoc* examination using a large data set like the Dundee Corpus.

2. Noun–Adjective order in French

Although there are exceptions, languages like English, German, Korean, Turkish, and many others, demand that an adjective pre-

[2] The possibility that violations to reading order might have adverse effects on comprehension has been addressed in the context of reading word strings (Kennedy & Murray, 1984; (Pynte, Kennedy, Murray, & Courrieu, 1988).