READING DURING THE COMPOSITION OF MULTI-SENTENCE TEXTS: AN EYE-MOVEMENT STUDY

Mark Torrance[1], Roger Johansson[2], Victoria Johansson[3], Åsa Wengelin[4]

[1]Corresponding author. Psychology Division, Nottingham Trent University and National Reading Research Centre, University of Stavanger. mark.torrance@ntu.ac.uk, +441158482467, no fax.

[2]Department of Psychology, Lund University

[3]Centre for Languages and Literature, Lund University

[4]Department of Swedish, University of Gothenburg

Writers composing multi-sentence texts have immediate access to a visual representation of what they have written. Little is known about the detail of writers' eye movements within this text during production. We describe two experiments in which competent adult writers' eye-movements were tracked while performing short expository writing tasks. These are contrasted with conditions in which participants read and evaluated researcher-provided texts. Writers spent a mean of around 13% of their time looking back into their text. Initiation of these look-back sequences was strongly predicted by linguistically important boundaries in their ongoing production (e.g., writers were much more likely to look back immediately prior to starting a new sentence). 36% of look-back sequences were associated with sustained reading and the remainder with less patterned forward and backward saccades between words ("hopping"). Fixation and gaze durations and the presence of word-length effects suggested lexical processing of fixated words in both reading and hopping sequences. Word frequency effects were not present when writers read their own text. Findings demonstrate the technical possibility and potential value of examining writers' fixations within their just-written text. We suggest that these fixations do not serve solely, or even primarily, in monitoring for error, but play an important role in planning ongoing production.

Keywords: Reading, Composition Writing, Reading during writing, Eye Movement

Text production proceeds as a series of bursts of transcription followed by pauses, with pausing more likely to occur at linguistically-significant boundaries – between clauses, sentences or paragraphs – than between or within words (Baaijen, Galbraith, & de Glopper, 2012; Sanders & Schilperoord, 2006; Wengelin, 2006). Mean sentence-initial latencies, for example, are typically in the region of 2s to 3s, but show substantial negative skew, with a non-negligible proportion of sentence-initial pauses being much longer. The cognitive activity that occurs during these pauses is not well understood. It is likely to involve the writer assessing the accuracy and appropriateness of the text-just-written, a function similar to the monitoring that occurs during speech production (Levelt, 1983; Postma, 2000), and planning the content and form of the text that will follow. Both of these functions – monitoring and planning – are potentially supported by the writer looking back at what they have just written. Pauses, at least at sentence boundaries and above, are typically sufficiently long to make it plausible that they are due, at least in part, to writers looking back into their text.

Study of readers' eye movements has produced a large body of research on the mechanisms that underlie reading (e.g., Engbert, Longtin, & Kliegl, 2002; Rayner, 1998). Some features of how the eyes move across text are common to most reading contexts. Other features vary according to reader purpose and text characteristics (e.g., Cauchard, Cane, & Weger, 2012; Kaakinen & Hyönä, 2014; Schad, Nuthmann, & Engbert, 2012; Schnitzer & Kowler, 2006). These studies have almost exclusively involved participants reading unfamiliar, researcher-provided texts. It is not clear whether eye-movement phenomena that have been established in this context generalize to situations in which subjects are in the process of composing a text and the text that they are attending to is within the document that they are writing (i.e. is the text that they have just written). Exploring this question is, in itself, psychologically interesting. It also needs addressing as a precursor to using eye-movement data of this kind to inform theories of how text is produced.

Readers (of unfamiliar, researcher-provided texts) make eye movements that consist of a series of saccades – rapid jumps from one location to another – and fixations, when the eyes are relatively stable. Letters and words are processed during fixations. Virtually no information is extracted during saccades. For skilled readers fixations last about 200-250 ms, forward saccades typically have amplitudes of 7-9 letters (Rayner, 1978, 1998; Starr & Rayner, 2001). These measures are affected both by the physical features of the word, particularly length, and by language-based characteristics, particularly word frequency and predictability. Fixation durations are longer for less frequent words (a proxy for word familiarity), even after control for length and other possible confounding factors (Inhoff & Rayner, 1986; White, 2008). These findings support a cognitive control account of eye movement during reading (Reichle, Pollatsek, Fisher, & Rayner, 1998): The length of time that gaze remains on a word, within a particular linguistic context, is an index of the amount of processing required for lexical retrieval and integration, at some level, into a higher-level representation of the text (Inhoff & Radach, 1998).

In contrast to the extensive literature exploring reading of researcher-provided texts, eye movement associated with written production has received little attention. Several papers have explored fixations on text that is being copied during copy-typing (Inhoff, Briihl, Bohemier, & Wang, 1992; Inhoff & Gordon, 1998; Inhoff, 1991). More recently, a number of studies have used eye-tracking methods to explore writing processes in contexts where the writers have some degree of choice over what they write. These have given some insight into how writers divide time between looking at reference materials and their own text (Alamargot, Dansac, Chesnet, & Fayol, 2007; Alamargot, Caporossi, Chesnet, & Ros, 2011), divide time between fixating monitor and keyboard (Johansson et al., 2010), plan single sentences (Nottbusch, 2010; Torrance & Nottbusch, 2012), make choices about when to correct errors (Van Waes, Leijten, & Quinlan, 2010), and make use of researcher-provided text when inflecting verbs (Alamargot et al., 2014).

We know of two published studies that report fixation measures for writers looking back into their own text during composition. Alamargot, Plane, Lambert, and Chesnet (2010) presented case studies of five writers that varied in age and expertise. They found that number and summed duration of fixations, controlling for text length, was greatest for the youngest and least experienced participant. Beers, Quinlan, and Harbaugh (2010) studied secondary school students who composed by dictation but viewed their text as it was typed. They measured time spent fixating text either close to or distant from the most recently typed word. 23% of time-on-task was associated with looking back into text already composed, and around two-thirds of these were local to the last-typed word.

These papers provide some insight into the nature of reading during writing but leave scope for further exploration. The lack of studies in this area, and the lack of sophistication in description of eye movement in existing studies in comparison to studies of reading in other contexts, are partly for technical reasons. Establishing which word is being fixated when there is a dynamic relationship between text and screen is not straightforward. With typed production – probably the dominant writing method for most adult writers and the focus of the present research – not only does the text develop down the screen, but editing, line wrapping, and scrolling move the text both horizontally and vertically in relation to screen coordinates. Matching of gaze to text as it develops or scrolls on the screen cannot be achieved by associating words with static areas of interest. This problem is not, however, insurmountable (Wengelin et al., 2009).

The research that we describe in this paper therefore explores the visual attention that competent adult writers give to their own text when "composition writing" (i.e. composing their own text in response to a general writing-brief, rather than copy-typing or completing sentence-stems). Specifically, we are interested in patterns of eye movement when writers pause during production and look back at the text that they just written[1]. We anticipate both similarities and

[1] We are not here concerned with fixations that occur concurrently with typing and/or on the word that is currently being typed, or fixations on the keyboard during typing. These are explicitly excluded from our analyses. We therefore analyse just situations in which the writer looks back into the text that they have already written. The nature and function of fixations on the word that is currently being typed are interesting but outside of present scope.

differences between the patterns of eye movements in this context and the eye movements of readers reading unfamiliar texts. Lexical retrieval mechanisms associated with word recognition, for example, are likely to remain the same regardless of the specific context in which the word is read. There are, however, at least two factors specific to attending to own-text that might affect eye movement patterns. First, the text is being read for a different purpose. Fixations within the sentence currently being produced, for example, are likely to serve functions directly associated with ongoing production, including supporting processing associated with inflecting verbs (Alamargot et al., 2014), supporting anaphoric reference, checking for or locating errors (Van Waes et al., 2010), and refreshing writers' representation of the syntax of the sentence that they are currently producing. Second, writers' own text is necessarily more familiar to them than if the text were provided by the researcher. Familiarity of own-text is likely to explain, for example, the fact that writers tend to miss errors when proofreading their own text (Daneman & Stainton, 1993). Inducing familiarity, by requiring that participants read the same text multiple times, may result in reduced fixation duration, fewer regressions, and increased saccade length (Jukka Hyönä & Niemi, 1990, but see Schnitzer & Kowler, 2006). These effects are likely to result from increased predictability (e.g., Smith & Levy, 2013), a potentially important mediator of the effects of reading own-text. In reading-during-writing contexts text written very recently may also directly prime lexical retrieval: words recently written may retain activation which results in faster recognition when they are fixated.

Our paper, therefore, provides relatively detailed description of writers' eye movements when they look back into the text that they have already produced. For comparison, we report the same measures for the same writers reading researcher-provided texts. This provides evidence for the validity of the methods that we are using. It also permits comparison, on the same measures, between eye-movement when reading and when writing. Differences are not, of course, surprising: composition writing and reading unfamiliar text are quite different tasks. Given the limited existing research exploring eye-movement in composition writing, however, it seems sensible to adopt eye-movement during reading, which is well theorized, as a reference behavior against which to contrast reading-during-writing.

Our aims are as follows: (a) to demonstrate that it is possible, from a technical perspective, to provide detailed and precise analysis of writers eye-movements as they look back into the text that they are composing; (b) to give a relatively detailed description of these eye movements, for competent adult writers composing multi-sentence, expository texts; and (c) to demonstrate that these data have the potential to contribute to understanding of how writers interact with and make use of their own, developing texts. We describe two studies. In the first, participants' eye-movements were recorded whilst writing, and whilst reading an unfamiliar text. The second followed a similar design but used methods which permitted more detailed analysis of word-level effects.

Experiment 1

In this first experiment we explored the reading activity of competent writers composing extended expository text on a familiar topic. Our aim was to answer the following questions: (1) To what extent do writers, in this context, engage in sustained reading of the text that they have already written? (2) When writers do read within their existing text, what proportion of eye activity is close to the word most recently typed, and what proportion is further into the existing text? (3) To what extent do fixation duration and saccadic amplitude, as indicators of processing difficulty, differ from those associated with normal reading? Comparison with the same participants reading a similar text both validated our operationalization of "sustained reading" and provided measures of fixation duration and saccade length against which to compare reading-during-writing.

1.1 Method

1.1.1 Design and Participants

Sixteen competent adult writers (university students, mean age = 31.6 years, SD = 10.5, 9 females) participated in the experiment. Participants were recruited from a pool of students who self-reported as fairly automatized typists. Findings from the experiment indicated that when keyboarding participants fixated the screen a mean of 65.1% of the time (SD = 15.7) and wrote relatively rapidly (M = 18.3 words per minute, SD = 7.5).

In the Writing task participants wrote an expository text discussing possible reasons for and solutions to problems associated with cheating and bullying in school. In the Reading-Only task they read the finished text produced by an earlier participant in the same study. Texts (both read and written) were in Swedish. Participants' eye movements were recorded throughout both tasks. All participants had Swedish as their first language, normal or corrected-to-normal vision, and at least two years of university study. No participants had language or linguistics as a major subject; or reading or writing difficulties. Data were collected in the Humanities laboratory at the Centre for Language and Literature, at Lund University, Sweden.

1.1.2 Apparatus and stimuli

The text-production task was performed on a personal computer equipped with *ScriptLog* software (Strömqvist & Karlsson, 2000). Scriptlog provides a simple text editor, with line wrapping and vertical scrolling. It captures and records all of the writer's keystrokes. The Reading-Only task was presented on the monitor of the same computer. We used a 19" monitor with the resolution set to 1024 x 768 pixels, with emerging text potentially filling the whole screen. 17 point Times New Roman font was used both for the Writing task and for the Reading-Only task.

Extended combined reading and typing tasks are difficult to perform if the participants' head position is fixed. This is partly because even competent touch-typists need occasionally to look down at the keyboard, but also and because the ergonomics of typing and looking at the screen means that fixing the head for a long period of time is distractingly uncomfortable. Participants were therefore equipped with the head-mounted SMI iView X (HED + HT 200 Hz) infrared pupil and corneal reflection imaging system. This comprised a bicycle helmet equipped with a scene camera and an eye camera. Magnetic head-tracking permitted definition of different areas of interest in the real world (monitor, keyboard or elsewhere) and, importantly, allowed the head and body to stay mobile. This set-up has a spatial resolution of about 1.0° and records data with a sampling frequency of 200Hz. Fixations were detected with an algorithm based on dispersion and duration with a dispersion threshold of 2° and a duration threshold of 80 ms.

The outputs of the combined keystroke-logging and eye-tracking system were as follows: (1) each keystroke or mouse event from the text-production task; (2) the temporal patterning of the keyboard and mouse events; (3) a video capture of the display overlaid with a gaze marker; (4) a data file with eye-movement coordinates for each participant. Analysis from these combined sources of data provided information about whether or not participants were fixating the word currently being typed and, if not, whether fixations were close to or at a distance from the last-typed word.

1.1.3 Procedure

Participants began the experiment by watching a short film showing various scenes from a school day dealing with typical problems such as bullying, cheating and stealing (also used by Berman & Verhoeven, 2002; Maggio, Lété, Chenu, Jisa, & Fayol, 2012). This served as a prompt and motivation for the task, but did not directly provide content. Participants were not expected to (and did not) directly communicate events from the video in their text. After the end of the film participants were fitted with the eye tracker helmet and were placed in front of a computer. The eye tracker was then calibrated and the participants were informed that their eye movements would be recorded during the entire experiment. They were then asked to write for 30 minutes and were informed when 5 minutes remained (although if a participant who required more time to finish their text they were not prevented from doing so). Eye-tracking data and keystroke data were recorded throughout.

After a break participants returned to the experiment, were recalibrated, and then completed the Reading-Only task. Participants were told that they were to read a text completed by another student on the same topic, with a view to evaluating its quality. After reading the text, participants answered questions evaluating the quality of what they had read.

Because of the use of independent head tracking, drift in eye-tracker calibration is virtually absent in the eye tracking system that we used and interruptions for recalibrations were therefore unnecessary. Calibration was checked at the end of each task. Our protocol was to exclude participants who no longer showed good calibration, but this did not prove necessary.

1.2 Analysis

Analysis of eye movement associated with the Writing task proceeded as follows: Eye movement and keystroke data were combined using custom software (Andersson et al., 2006) to generate a temporally ordered representation of what the writer looked at and what keys they pressed. For a detailed description of this method, see Wengelin et al. (2009). Because our focus was on reading activity that occurred during breaks in ongoing production, we then excluded from analysis all fixations for which the period between fixation onset and fixation offset overlapped with keyboard activity. We also ignored all fixations that were not on the computer screen. Within the remaining fixations we differentiated between (a) fixations that were and were not part of a reading sequence and (b) reading sequences that were local to the most recently typed word, and fixations that were distal (see below).

A fixation was identified as part of a “sustained reading” sequence if and only if all four of the following conditions were met: (1) It was part of a series of three or more consecutive fixations; (2) Saccades between these fixations involved forward moves (left to right) within the text on the same line; (3) Saccadic amplitude was not longer than 100 mm, which corresponded, on average to 25 letter spaces (use of a proportional font meant that the exact number of characters fluctuated slightly), and (4) none of the fixations in the sequence were on the word currently being written.[2]

Fixations were categorized as being associated with *local reading* if they were part of a reading sequence that was within the same line as the word currently being composed. Fixations were categorized as *distal reading* if they were part of reading sequences on text that occurred in the text prior to the line that contained the last-typed word.

Eye movements during the Reading-Only task were also analyzed according to whether or not fixations occurred within a reading sequence. The local / distal distinction is not relevant in this context. Eye movements during the Reading-Only and the Writing tasks were compared in terms of the proportion of fixations occurring within a reading sequence. This served as a check on the validity on the "reading sequence" definition as an indicator of sustained reading activity.

1.3 Results

The majority of on-screen fixations during the Reading-Only task were part of reading sequences (M = 72.3%, SD = 5.3%, with a maximum of 81.7% and minimum of 67.6%; overall 3697 fixations

---

[2] This definition of sustained reading has previously been used to differentiate between reading and scanning behavior in newspaper reading (Holmqvist, Holsanova, Barthelson, & Lundqvist, 2003) and is consistent with how eye movement patterns have been characterized in previous reading research (cf. Engbert et al., 2002; Rayner, 1998). Rayner (1998), summarizing existing research, reports that when reading English, eye movement patterns are to a large degree characterized by saccades moving from left to right on the same line and further demonstrates that saccadic amplitudes above 25 letter spaces are virtually absent in such sequences (Rayner, 1998, figure 1). Regressions (saccades moving from right to left along the same line or back to previous lines) and return sweeps (saccades from the end of one line to the beginning of the next) are thus not included in this definition of sustained reading.

out of 5082 fixations on the display). When performing the Writing task this dropped to a mean of 8.4% (SD = 6.0%; overall 4880 fixations out of 50030 detected fixations on the display), and varied substantially across participants with a maximum of 44.6% and a minimum of 3.0%. Reading sequences took up a mean of 5.8% of total time-on-task (SD = 4.8%, maximum = 17.4%, minimum = .5%). Of the fixations that were classified as being part of a reading sequence, a mean of 68% (SD = 24%) were local (within the same line as the last-typed word) and 32% (SD = 24%) were distal.

Mean fixation duration in the Reading-Only task was 203ms (SD = 33) compared to 235ms (SD = 51) for local reading and 201ms (SD = 27) for distal reading during the Writing task. This represented a significant main effect of task ($F(1,15) = 7.098$, $p < .01$, partial $\eta^2 = .321$) with fixations during local reading significantly longer than distal reading or for reading sequences in the reading condition (Bonferroni post-hoc tests, $p < .05$). There was no statistically significant effect of condition on saccadic amplitude (Reading-Only task, M = 31.8, SD = 5.1, approximately 8.0 characters; Writing task, local reading, M = 31.6, SD = 5.6; approximately 7.9 characters; Writing task, distal reading, M = 34.1, SD = 8.0, approximately 8.5 characters).

1.4 Discussion

72% of eye activity in the Reading-Only task was associated with patterns that fitted our operational definition of "sustained reading". This suggests that this definition captures the majority of activity associated with participants reading researcher-provided text. Reading that was distant from the sentence that was currently being worked on appeared to follow similar patterns to reading of unfamiliar text: Mean fixation durations and saccade lengths were similar. Differences might have been expected here, given that writers' own text is more familiar and therefore predictable than is text researcher-provided text. This (putative) effect may, however, have been counteracted by the fact the reading own text during production is initiated in response to a specific writer purpose – error checking, search for new content, and so forth – activities that may require greater attention and processing than just reading text for comprehension.

Our findings suggest that during writing (by competent writers completing an expository writing task) only a relatively small proportion of eye activity within text-already-written was associated with sustained reading sequences. The majority of this activity was local (i.e. within the same line as the last-typed word). The ratio of local to distal fixations in the present experiment (2.1) was rather higher than the 1.6 for younger writers found by Beers et al. (2010), although the methods used in that study (observing while text was transcribed by an amanuensis) make these values difficult to compare. Reading within words close to the most-recently typed word involved fixation durations that were longer than fixations during distal reading, by a mean of 32ms. The fact that local fixations tended to be longer suggests, again, that reading local text might serve functions other than simply establishing what the text says. Again, two, mutually compatible possibilities are that these fixations are associated with monitoring (for errors and/or for fit to intended message), and that they support planning of what the writer will say next.

From a methodological point of view Experiment 1 demonstrated, in the context of typewritten production, the feasibility of robust and meaningful measures of writers' eye movement as they look back into the text that they are currently composing. This shows the potential for more-or-less automatic coding of eye-movement data when the fixated object is dynamic text. We developed these methods further in Experiment 2. Findings from Experiment 1 give, we believe for the first time, eye-movement based estimates of where and for how long writers read within this text. Experiment 2 aimed to provide a more detailed account of the relationship between typing and reading activity and, by relating specific fixations to specific words, to establish the extent to which fixated words were lexically processed.

Experiment 2

Experiment 2 again explored visual attention to already-written text during composition writing. It differed from Experiment 1 in three important respects. First, methods used in Experiment 2 made it possible to explore the association between reading activity during writing and ongoing production. As we have noted, writers tend to pause for longer at higher-level text boundaries (sentence > word > character). We predicted a similar pattern for the probability of look-back and for the distance into the existing text where these fixations occurred.

Second, the methods that we adopted gave information about exactly which word in the text was being fixated. This made possible analysis of fixation duration in terms of word length and frequency. If fixation measures are affected by the length and/or frequency of the fixated word this represents evidence that the word has, in fact, been processed lexically. When writers look back within their text it is not clear, on the basis of the findings from Experiment 1, to what extent they are processing the words that they fixate. Fixations when participants look back into their text may be associated with semantic and lexical processing of the fixated word (as in the case in reading for comprehension). However, it is also possible that they serve a useful function that is not associated with lexical and semantic processing. For example, there is evidence that during composition purely spatial characteristics of the just-written text – how paragraphs appear on the page, for example – provide information that is important for maintaining and developing a mental representation of what has been written (Le Bigot, Passerault, & Olive, 2011, 2012). Also, it may simply be that fixations are epiphenomenal or artefactual. In both of these cases we would not expect to see frequency and length effects.

Third, reading-during-writing was contrasted with an editing task in which participants read and made changes to a researcher-provided text. This ensured a greater overlap in the likely function or purpose of reading activity across the two tasks than perhaps was achieved in Experiment 1.

2.1 Method

2.1.1 Design and participants

Participants performed a Composition-Writing task and a Read-and-Edit task. The Composition-Writing task involved writing in response to the following prompt: *Write an essay designed to convince people that petrol prices should be increased to reduce global warming.* Participants were asked to produce good quality, polished text. The resulting texts had a mean length of 410 words (SD = 169), and all were, subjectively, coherent. Participants' eye movements were tracked and keystrokes logged throughout both tasks. The Read-and-Edit task involved reading a 380 word, two-paragraph text modified from an academic paper discussing the relationship between self-esteem and performance – a topic that would be relatively easily understood by participants. The first paragraph was well-formed and error-free. The second paragraph contained several spelling errors and some clumsy expression. Participants were asked to read the text and make any changes that they thought necessary to improve its quality.

Tasks were in English and were completed by 10 competent, undergraduate and postgraduate adult writers (Mean age = 21.2, SD = 5.7, 6 female). All participants had English as their first language and normal or corrected-to-normal vision. All reported using word-processing software as their default writing tool, and none reported or showed any specific reading or writing difficulties. Data were collected in the eye tracking laboratory in the Psychology Division at Staffordshire University, UK.

2.1.2 Apparatus

Texts were read and composed on a 21 inch, 4:3 CRT monitor running at a resolution of 1240 by 768 in 12pt Courier New with 18 pixels between lines. Characters therefore subtended a visual angle of .48° in the x axis. For purpose of analysis a fixation was associated with a specific character if it was recorded within an area tightly bounded around the character in the x axis (and excluding any adjoining whitespace) and extending 18 pixels above and below the line. The effective interest area around a four-letter word was therefore approximately 1.4° of visual angle in both x and y dimensions.

Eye movements were recorded using an EyeLink2 eye tracker (SR Research Ltd., Mississauga, Ontario, Canada). This is a head mounted, infrared, video-based system with imaging of pupil and of corneal reflection. Head movement is monitored and then controlled for when computing gaze location. This permitted recording at a temporal resolution of 500Hz and a spatial resolution of about .5°. Fixations were identified by the SR Research default saccade-picking algorithm, with saccade velocity and acceleration threshold of, respectively, $30°s^{-1}$ and $8000°s^{-2}$ and a motion threshold of .15°.

Data were captured using an in-house text editor program running within the SR Research *Experiment Builder* environment. The program, which is described in more detail in Wengelin et al. (2009), gave fixation location referenced to the text. In contexts where participants read experimenter-provided text this information is typically provided by defining screen-referenced (pixel) locations around all or some words as areas of interest. In contexts where the text is being concurrently created or modified by the participant, this strategy will not work because what appears on the screen changes unpredictably as the task proceeds. The program used in this experiment provided a simple text editor, with an appearance similar to, for example, MS Notepad, that logged both keystroke and fixation data. The editor line-wrapped and text could be scrolled. In a second, analysis stage keystroke data were used to provide a reconstruction of the text, including the location of each character on the screen at the onset time of each fixation. We were therefore able to extract, at any particular point in time, both the text of the word (and sentence) currently being fixated (i.e. data equivalent to that afforded by pre-defining words-as-areas-of-interest in a typical reading experiment), and what the participant was currently typing or had most recently typed.

2.1.3 Procedure

Participants were fitted with the eye tracker head mount and the tracker was calibrated. They then completed a short writing and editing task to familiarize themselves with the text editor controls. They were then given a maximum of 10 minutes to complete the Read-and-Edit task. After a short break the eye-tracker was recalibrated and they completed the Composition-Writing task. Participants were not given advance warning of the topic of the Composition-Writing task, and were free to write as soon as the writing prompt appeared at the top of the editor screen. Participants were given 30 minutes to complete the task.

Calibration drift was monitored by the researcher who viewed estimated fixation location and text editor display on a separate screen. If the researcher detected drift they initiated a drift check. This procedure was relatively nonintrusive, requiring that the participant briefly stop writing and fixate the cursor (a target with known screen location that was close to the participant's gaze). If this process identified drift it was immediately and automatically followed by a single-point drift correction, again at the cursor location. Drift checks were initiated on average 5.6 times per participant across the two tasks (SD = 2.3). In 18% of these cases single-point drift-correction was required, and in all cases this corrected drift. Fixations associated with drift check and correction were omitted from analysis.

2.1.4 Data

Mean total time-on-task for the Read-and-Edit task was 7min 32s (SD = 2min 27s) and for the Composition-Writing task was 19min 10s (SD = 5min 3s), timed from start of task to final keystroke.

Eye movement took four main forms: gazing at the keyboard during typing, gazing at developing words as they emerge on the screen during typing, monitoring the location of the cursor during cursor moves (so that it can be correctly located for editing), and fixations within the text-already-written. It is just this within-text activity that is relevant to our present purpose.

We identified fixations as *within-text* if and only if all four of the following conditions were met: (a) the fixation was on the part of the screen containing text, (b) the fixation was not on the word currently containing the cursor, (c) the event immediately preceding the fixation was not a cursor move, and (d) condition c also held for the immediately preceding and following fixations. Using this definition, mean total time associated with within-text fixations was 3min 29s (SD = 1min 17s) for the Read-and-Edit task and 2min 28s (SD = 1min 15s) for the Composition Writing task. This represented a mean of 54% (SD = 9%) of total time-on-task for the Read-and-Edit task, and, as might be expected, much less for the Composition-Writing task (M = 13%, SD = 4%).

Word frequencies (surface form) were taken from the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) and were log-transformed. Mean frequency (averaging across types rather than tokens), for open-class words, was 226 for the text given to students in the Read-and-Edit condition, and slightly lower (M = 195, SD = 11.9) for the texts written in the Composition Writing condition.

2.2 Analysis and Results

We divide reporting of findings into two sections. We first explore "writing location" effects in just the Composition Writing task. We then describe differences in various eye-movement measures, and the effects of the frequency and length of the fixated word, depending on whether the fixation was distal or local, and whether or not it was part of a reading sequence, making comparisons across tasks.

Analysis took within-word runs as a basic unit. A run comprised the first fixation on a word and any subsequent fixations before the eye exited that word (either forwards or backwards). Mean numbers of runs were 796 (SD = 270) for the Read-and-Edit task and 617 (SD = 335) for the Composition-Writing task. As in Experiment 1 we identified patterns of eye movement that could be interpreted as sustained reading sequences. We operationalized these as a series of not less than three consecutive runs linked by forward saccades of not more than 25 characters. "Forward" was defined in relation to the text rather than the x axis: Reading sequences could include saccades that moved gaze to the start of the next line. A reading sequence is show in the example in Figure 1.

[insert Figure 1 near here]

2.2.1 Writing-location effects

Analysis in this section draws on data from just the Composition Writing task. This analysis explored questions about whether the place where the writer has currently got to in producing their text – whether they are within a word, at a word boundary, or at a sentence boundary – affects the probability that they will look back into their text and features of their eye movements when they do so. Dependent variables were drawn from eye activity associated with participants looking back into their text during the period between pressing the first and second key at a specific boundary. See Figure 1 for an example.

[Table 1 near here]

For the purpose of this analysis the basic unit was the boundary between two keystrokes. We identified six text locations (illustrated in column headers in Table 1): *within word*, *word-terminal* (after keying the last character in a word, but before keying the space), *word initial* (after the space but before the next word), *sentence terminal* (after end of last word in a sentence, but before the sentence-terminal punctuation – typically a full-stop/period or question mark), *after sentence-terminal punctuation* (between sentence-terminal punctuation and the space), and *sentence initial* (between the space that the first word of the new sentence, as in Figure 1). Boundaries were included in this analysis only if the string associated with the boundary was produced without editing or deletion. So, for example, at a sentence boundary, all four of the associated key presses (word terminal, punctuation, space, word initial) had to be created without intervening delete or cursor actions. This means that eye activity that resulted in error correction or other editing (e.g., looking back and then changing a word earlier in the sentence) was excluded from this analysis. We also excluded situations in which writers were not typing at the front edge of their text and looked forward rather than backwards. Paragraph-level boundaries, though potentially interesting, were insufficiently frequent, by-subject, to make statistical inference possible, and so were omitted.

Statistical analysis was by linear mixed-effects regression, starting with an intercept-only model with random by-subject intercepts, and then adding the text-boundary factor. Parameter estimates from this second model are given in Table 1. Models were compared using chi-square change tests, based on difference in log likelihood ratio. Statistical significance of parameter estimates was derived from z tests based on the parameter estimate and its associated standard error.

The probability that writers looked back (i.e. made any fixations behind the word that they were currently writing or had just completed) was strongly affected by boundary location ($\chi^2(5) = 27$, $p < .001$ for the full model compared with intercept-only, using binomial logistic methods). As can be seen from Table 1, only 7% of mid-word boundaries were associated with look-back. This increased slightly at word boundaries, and substantially at sentence boundaries. Combining probabilities across the three sentence-boundary locations suggests that writers looked back on 75% of occasions when they were between sentences.

For the remainder of analyses, we analyze just those situations where a text boundary was associated with look-back.

<u>Total number of fixations</u>. This was affected by text boundary location ($\chi^2(5) = 167$, $p < .001$), with more fixations (i.e. more extensive look-back) occurring at higher-level boundaries. Differences, relative to within-word, were statistically reliable (after Bonferroni correction) at word-initial and sentence-initial boundaries.

<u>Probability that look-back included one or more reading sequences</u>. Again this showed a strong effect of boundary location ($\chi^2(5) = 18$, $p = .002$ for the full model compared with intercept-only, using binomial logistic methods). When writers looked back from within a word there was only a 1% chance that their eye movements would form a reading sequence. Probability increased at word boundaries and sentence boundaries. Reading sequences occurred in an estimated 29% of

the situations in which writers looked back immediately prior to starting the first word of a new sentence.

Distance of fixation from point of inscription. This explored whether writers tended to look further back into their text dependent on text-boundary. Mean distance of fixations from point of inscription (i.e. distance from text-boundary) was strongly positively skewed, and therefore log transformed. We found a statistically significant effect of text-boundary on mean distance ($\chi^2(5)$ = 32, $p < .001$). Mean distance varied between 9 and 11 words, with slightly greater distances at sentence boundaries. However, confidence intervals were broad, with only distance from word-initial text boundaries showing a statistically reliable difference relative to within-word.

First-fixation duration and gaze duration. We found no statistically significant effects of text boundary on either mean first-fixation duration or mean gaze duration per word.

2.2.2 Reading Sequence and Distal vs. Local effects

In this section we explore the effects of the three-way interaction between task (Read-and-Edit vs. Composition-Writing), whether or not a fixation was part of a reading sequence, and whether the fixation was local to or distant from the cursor. The methods made possible a more linguistically-relevant operationalisation of the local/distal distinction: A run was local if it fell within the same sentence as the last-typed character, and distal if it did not.

[insert Table 2 near here]

Table 2 gives the proportion of runs in each of the eight cells of the task by reading/not-reading by local/distal interaction. In the Composition-Writing condition a mean of 37% of in-text fixations were classified as part of either local or distal reading sequences. This indicates a mean of 4.8% of total time-on-task spent reading already-produced text, a value very close to that found in Experiment 1. Distal reading sequences were much more probable for the Read-and-Edit task than in the Composition-Writing task ($t(9) = 7.0$, $p < .001$). This finding was expected given that the Read-and-Edit condition required sustained reading of the text before it could be evaluated and edited. Sustained reading is not necessitated in the same way by the Composition Writing task. Local non-reading activity (isolated fixations on the immediately preceding text) was more common during Composition Writing than during the Read-and-Edit task ($t(9) = 6.2$, $p < .001$). There was no effect of task on the extent to which participants either read locally or made isolated (non-reading) distal fixations.

We modelled first-fixation duration, gaze duration, and fixations-per-word, as follows: We started with a zero model with random by-subject and by-word intercepts (Model 0). We then added a fixed effects for task, reading-sequence, and the local/distal distinction, including 2-way and 3-way interactions (Model 1), then interactions with word frequency (Model 2), and with word length (Model 3). The inclusion of length and frequency as covariates served both to assess their effects and to provide statistical control for possible confounding effects on estimates of cell means. Model fits and χ^2 change test results can be found in Table 3. To permit evaluation of the effects of length and frequency whilst reducing confound with syntactic function, this analysis was just of runs on open-class words (nouns and non-auxiliary verbs).

[insert Table 3 near here]

On the basis of parameter estimates from the final models (Model 3) we calculated predicted means for each of the eight cells of the Task by Reading-Sequence by Distal/Local interaction. These are given in Table 4. Table 5 reports estimated effects of length and frequency of the fixated word. For simplicity, for the Read-and-Edit task we report only values for distal reading sequences. This "reading-for-editing" provides a reference behavior that is close to "normal" sustained reading in the context of a task where the reader is specifically reading with a view to editing. Statistical significance of parameter estimates were determined by z tests based on the parameter estimate and its associated standard error. For predicted means (Table 4) this tested the null hypothesis that the mean for that cell is equal to the mean for the reading-for-editing condition. For effects of length and frequency (Table 5), this tested the null hypothesis that the effect was zero within that cell.

[insert Tables 4 and 5 near here]

First-fixation duration. In the Composition Writing condition first-fixation duration was unaffected by any combination of factors. First fixations were shorter for high frequency words when reading-for-editing.

Gaze duration. Gaze duration showed several effects, with the full model, including task, length, and frequency effects, giving best fit. As can be seen from Table 4, gaze duration was significantly shorter during Composition Writing than when reading-for-editing condition except where runs were associated with isolated (non-reading-sequence) glances back to words in the current sentence (constraining Model 3 to make gaze duration equal for local and distal non-reading runs in the Composition Writing task gave significantly poorer fit: $\chi^2(1) = 7.8$, $p = .005$). This trend was also present for gaze duration in reading sequences but was not statistically significant. Again, there was evidence of an effect of word frequency in the reading-for-editing condition, but again this effect was absent for Composition Writing (Table 5).

Fixations-per-run. Effects on number of fixations per run were also relatively strong, with the full model (Model 3) providing best fit. Words received significantly fewer fixation, on average, in the Composition Writing task than during reading-for-editing. Isolated (non-reading-sequence) glances at local words were more likely to involve more than one fixation than isolated glances on distal words (constraining Model 3 as above: $\chi^2(1) = 9.2$, $p = .003$). Longer words tended to receive more fixations in all conditions (Table 5). After control for word length there were no effects of word frequency, even in the reading-for-editing condition.

2.3 Discussion

Probability of look-back was strongly predicted by where the participant was at in their ongoing production: Participants were very unlikely to look back into their existing text from the middle of a word that they were writing, but were very likely to look back when at a sentence boundary. It is worth exploring why this might be the case. Language planning scope, at both conceptual and syntactic levels, is typically over units greater than single words. This is true for speech (e.g., Lee, Brown-Schmidt, & Watson, 2013; Smith & Wheeldon, 1999) and probably true for writing (Torrance & Nottbusch, 2012). Although planning scope is likely to extend over units smaller than (syntactic) sentences, all existing accounts point towards clause boundaries coinciding with the start of a syntactic planning unit. Sentence boundaries therefore provide a point at which writers can receive new input from already-written text without this interfering with a currently-active plan. This opportunity can then be used for checking preceding text for errors and/or to provide direct input into the planning of what will be written next.

Look-back typically appeared to be associated with some level of lexical processing of fixated words. This was true even when writers' fixations were associated with "hopping" (isolated glances into the text and not part of sustained reading sequences) and during sustained reading. In the Composition Writing task first-fixation durations were similar to those when reading-to-edit and to those found in other studies in which participants read extended text (e.g., Pynte, New, & Kennedy, 2008a, 2008b). This was true regardless of whether the word being fixated was local or distal or whether or not fixations were part of a reading sequence. We also found significant length effects for all categories of fixation during Composition Writing. Taken together these findings suggest that once a word was fixated this initiated processes associated with lexical retrieval. Some "hopping" fixations are likely to have been initiated by a writer's need (and intention) to locate the cursor when looking up from the keyboard. The fact that even isolated fixations appeared to be associated with lexical processing of fixated words and with relatively long fixations, suggests either that these cursor-search fixations were relatively rare or that when gaze landed on a word it was unavoidably processed. If the latter, then this suggests that fixation sequences that start as cursor-search may then take on an additional monitoring or planning role.

Comparison between distal and local fixations associated with "hopping" (fixations that were not part of sustained reading sequences) suggests that local fixations were associated with more extensive processing. We found a similar effect for local reading sequences in Experiment 1. One possible function for this activity is that it may serve to cue subsequent production, perhaps helping to keep active a semantic representation of the current message, thus freeing up resources for linguistic processing. We discuss this in more detail below. Longer fixations may also serve a monitoring and correction function.

Gaze duration were shorter and fixations-per-run were fewer when composing relative to reading-for-editing. A similar effect was found in Experiment 1. This may be due to increased familiarity, and therefore predictability, of self-written text, consistent with Hyönä & Niemi (1990). It may also result for differences in reading purpose. For possibly similar reasons, we found frequency effects on both gaze duration and fixations-per-run during reading in the Read-and-Edit task but not in the Composition Writing task. The lack of frequency effects when participants reading their own text may be explained by the fact that the frequency with which a word appears in printed English is a poor proxy for familiarity when we know that the writer has, in fact, recently retrieved the word to include in their own text. Words that the writer has used are likely to have greater familiarity than would be predicted by their frequency, both as a result of recent retrieval and because the fact that the writer has included a specific word in their text means that it must be reasonably accessible.

General Discussion

The research reported in this paper involved competent adult writers composing text on a familiar topic and possibly with relatively low investment in the finished product. Texts were written with little substantive revision. The eye movement that we sampled were therefore associated with ongoing production. Within this specific context, our findings suggest three general conclusions.

First, writers spent a small but non-negligible amount of time looking back into their text. In both Experiments 1 and 2 around 5% of time-on-task was associated with patterns of eye movement which we characterized as sustained reading. An additional 8% of time-on-task was associated with look-back sequences in which writers hopped backwards and forwards among words without sustained reading (Experiment 2).

Second, mean fixation durations and length effects on numbers of fixations-per-run (Experiment 2) suggest that fixated words were typically processed lexically. This was true not just in reading sequences but also for non-reading-sequence fixations. Eye-movement that involved hopping around within the text cannot, therefore, be dismissed as random or unfocussed. At least some of the time, fixated words appeared to be attended to and processed.

Third, *when* a writer looked back into the text was strongly predicted by where the writer was at in their ongoing production: Look-back was both much more common, and deeper into the existing text when it occurred between sentences than when it occurred at lower-level boundaries. This suggests that looking back into already-written text is in some way functionally implicated in ongoing production.

One probable reason for fixations within the already-written text is checking for errors. We cannot rule out the possibility that this is their sole function. However we think that this is unlikely. In both experiments participants' texts were error prone, but it was common for writers to look back within their text and not correct errors. Error correction was frequently delayed until the end of the task, with the writer then reading through the complete text making minor edits. It is also difficult to see a role for non-reading "hopping" sequences in error checking. The "writing-location" effects reported in Table 1 explicitly excluded situations where look-back resulted in editing. Look-back was, however, both much more common and much more extensive in the sentence-initial position. This, combined with the fact that message planning is more likely to be associated with sentence boundaries than at lower level text boundaries, suggests a planning function for sentence-initial look-back.

It seems probable, therefore, that at least on some occasions looking back into the existing text is associated with the writer planning what to say next. Figure 2 shows the first part of a long sequence of eye movements initiated immediately after completing a sentence. The writer made no changes to their existing text at any point during this sequence. The sequence starts with a fixation on “temperatures” (Panel A) which was the theme of the just-completed sentence, and that becomes the theme for the next sentence when it was eventually written. They then read their most recent sentence in its entirety, with “temperatures” being given additional attention (three fixations, including one internal regression; Panel B). The writer then makes a series of saccades between the end of the sentence and “temperatures”, and then looks back at two isolated phrases, three and two sentences back into their text (Panel C). These two phrases, although in different sentences, are closely semantically related. The sequence continued in a similar vein for a further 193 fixations, in which the writer’s gaze returned to “temperatures” a further 16 times, interspersed with isolated fixations and short reading sequences within the preceding 4 sentences. This kind of sequence – multiple saccades from the front edge of the text to words or phrases within the text-already-written, and without editing – although unusually long in this instance, was common across writers in both experiments.

The processes by which writers plan what to say may sometimes involve strategic and explicit thinking and reasoning (Flower & Hayes, 1980). However, a large part of ongoing production, including content determination, is likely to result from implicit, low-level and possibly parallel processing (Maggio, Lété, Chenu, Jisa, & Fayol, 2012; Olive, 2014; Torrance, 2015; cf., Pickering & Garrod, 2004, in spoken production). Look back may, therefore, be a behaviour triggered implicitly by the need for new content and resulting (sometimes but not always) in priming what to say next. Preceding text is likely to be rich in cues to relevant new content. It is also possible that, rather than providing input to planning mechanisms, writers’ gaze may be drawn to what they are already thinking about, by processes analogous to those occurring in visual world paradigm studies of comprehension (reviewed, for example, by Huettig, Rommers, & Meyer, 2011). However, regardless of whether look-back provides input to planning or just tracks internal planning process, a writer’s gaze allocation is a potential source of insight into what these planning processes might be like. Our present findings do not directly address questions about how text is planned. They do, however, suggest that study of writers' eye movements has the potential to make a contribution in this area. Future research might usefully explore both the detail of the relationship between which words are fixated during look-back and the meaning and syntax of the next-produced sentence.

In conclusion, therefore, this study builds on previous literature demonstrating the feasibility of tracking writers' eye movements within their own text during production, providing more detailed information about which words are fixated when and for how long than has previously been available. Information about how often writers look back within their own text, the duration and depth within the text of these look-back sequences and, importantly, the detail of the relationship between what is fixated and what is written next, provides insight not just into how writers read and edit their existing text, but also into the as yet poorly understood processes that permit ongoing production. We hope that the methods and findings detailed in this paper will provide impetus for further research in this area.

References

Alamargot, D., Caporossi, G., Chesnet, D., & Ros, C. (2011). What makes a skilled writer? Working memory and audience awareness during text composition. *Learning and Individual Differences*, *21*(5), 505–516. doi:10.1016/j.lindif.2011.06.001

Alamargot, D., Dansac, C., Chesnet, D., & Fayol, M. (2007). Parallel processing before and after pauses: A combined analysis of graphomotor and eye movements during procedural text production. In M. Torrance, L. Van Waes, & D. Galbraith (Eds.), *Writing and Cognition: Research and Applications* (pp. 13–29). Amsterdam: Elsevier.

Alamargot, D., Flouret, L., Larocque, D., Caporossi, G., Pontart, V., Paduraru, C., … Fayol, M. (2014). Successful written subject–verb agreement: an online analysis of the procedure used by students in Grades 3, 5 and 12. *Reading and Writing*, *28*, 291–312. doi:10.1007/s11145-014-9525-0

Alamargot, D., Plane, S., Lambert, E., & Chesnet, D. (2010). Using eye and pen movements to trace the development of writing expertise: Case studies of a 7th, 9th and 12th grader, graduate student, and professional writer. *Reading and Writing*, *23*, 853–888. doi:10.1007/s11145-009-9191-9

Andersson, B., Dahl, J., Holmqvist, K., Holsanova, J., Johansson, V., Karlsson, H., … Wengelin, Å. (2006). Combining keystroke logging with eye tracking. In L. Van Waes, M. Leijten, & C. Neuwirth (Eds.), *Writing and Digital Media* (pp. 166–172). Amsterdam: Elsevier.

Baaijen, V. M., Galbraith, D., & de Glopper, K. (2012). Keystroke Analysis: Reflections on Procedures and Measures. *Written Communication*, *29*(3), 246–277. doi:10.1177/0741088312451108

Baayen, R. H., Piepenbrock, R., & Gulikers, L. (1995). *The CELEX lexical database*. Philadelphia: University of Philadelphia, Linguistic Data Consortium.

Beers, S. F., Quinlan, T., & Harbaugh, A. G. (2010). Adolescent students' reading during writing behaviors and relationships with text quality: an eyetracking study. *Reading and Writing*, *23*(7), 743–775. doi:10.1007/s11145-009-9193-7

Berman, R., & Verhoeven, L. (2002). Cross-linguistic perspectives on the development of text-production abilities: Speech and writing. *Written Language & Literacy*, *5*(1), 1–43. doi:10.1075/wll.5.1.02ber

Cauchard, F., Cane, J. E., & Weger, U. W. (2012). Influence of Background Speech and Music in Interrupted Reading: An Eye-Tracking Study. *Applied Cognitive Psychology*, *26*(3), 381–390. doi:10.1002/acp.1837

Daneman, M., & Stainton, M. (1993). The generation effect in reading and proofreading. *Reading and Writing*, *5*(3), 297–313. doi:10.1007/BF01027393

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision Research*, *42*(5), 621–636. doi:10.1016/S0042-6989(01)00301-7

Flower, L., & Hayes, J. (1980). The dynamics of composing: Making plans and juggling constraints. In L. W. Gregg & E. R. Steinberg (Eds.), *Cognitive processes in writing* (pp. 31–50). Hillsdale, N.J.: Erlbaum.

Holmqvist, K., Holsanova, J., Barthelson, M., & Lundqvist, D. (2003). Reading or scanning? A study of newspaper and net paper reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research* (pp. 657–670). Amsterdam: North Holland.

Huettig, F., Rommers, J., & Meyer, A. S. (2011). Using the visual world paradigm to study language processing: a review and critical evaluation. *Acta Psychologica*, *137*(2), 151–71. doi:10.1016/j.actpsy.2010.11.003

Hyönä, J., & Niemi, P. (1990). Eye movements during repeated reading of a text. *Acta Psychologica*, *73*(3), 259–280. doi:10.1016/0001-6918(90)90026-C

Inhoff, A. (1991). Word-Frequency During Copytyping. *Journal of Experimental Psychology-Human Perception and Performance*, *17*(2), 478–487. doi:10.1037/0096-1523.17.2.478

Inhoff, A., Briihl, D., Bohemier, G., & Wang, J. (1992). Eye-Hand Span and Coding of Text During Copytyping. *Journal of Experimental Psychology-Learning Memory and Cognition*, *18*(2), 298–306. Retrieved from <Go to ISI>://A1992HG32900006

Inhoff, A., & Gordon, A. (1998). Eye Movements and Eye-Hand Coordination During Typing. *Psychological Science*, *6*(6), 153–157. doi:10.1111/1467-8721.ep10772929

Inhoff, A., & Radach, R. (1998). Definition and computation of oculomotor measures in the study of cognitive processes. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 29–54). Oxford: Elsevier.

Inhoff, A., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: effects of word frequency. *Perception & Psychophysics*, *40*(6), 431–9. doi:10.3758/BF03208203

Johansson, R., Wengelin, Å., Johansson, V., Holmqvist, K., Wengelin, A., Johansson, V., & Holmqvist, K. (2010). Looking at the keyboard or the monitor: relationship with text production processes. *Reading and Writing*, *23*(7), 835–851. doi:10.1007/s11145-009-9189-3

Kaakinen, J. K., & Hyönä, J. (2014). Task relevance induces momentary changes in the functional visual field during reading. *Psychological Science*, *25*(2), 626–32. doi:10.1177/0956797613512332

Le Bigot, N., Passerault, J.-M., & Olive, T. (2011). Implication of visuospatial and temporal information in memory for word location. *Journal of Cognitive Psychology*, *23*(4), 522–530. doi:10.1080/20445911.2011.532119

Le Bigot, N., Passerault, J.-M., & Olive, T. (2012). Visuospatial processing in memory for word location in writing. *Experimental Psychology*, *59*(3), 138–46. doi:10.1027/1618-3169/a000136

Lee, E.-K., Brown-Schmidt, S., & Watson, D. G. (2013). Ways of looking ahead: hierarchical planning in language production. *Cognition*, *129*(3), 544–62. doi:10.1016/j.cognition.2013.08.007

Levelt, W. J. M. (1983). Monitoring and self-repair in speech. *Cognition*, *14*, 41–104. doi:10.1111/0023-8333.00090

Maggio, S., Lété, B., Chenu, F., Jisa, H., & Fayol, M. (2012). Tracking the mind during writing: Immediacy, delayed, and anticipatory effects on pauses and writing rate. *Reading and Writing*, *25*, 2131–2151. doi:10.1007/s11145-011-9348-1

Nottbusch, G. (2010). Grammatical planning, execution, and control in written sentence production. *Reading and Writing*, *23*(7), 777–801. doi:10.1007/s11145-009-9188-4

Olive, T. (2014). Toward a Parallel and Cascading Model of the Writing System: A Review of Research on Writing Processes Coordination. *Journal of Writing Research*, *6*(2), 173–194.

Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences*, *27*(2), 169–226. doi:10.1017/S0140525X04000056

Postma, A. (2000). Detection of errors during speech production: a review of speech monitoring models. *Cognition*, *77*(2), 97–131. Retrieved from <Go to ISI>://000090031700002

Pynte, J., New, B., & Kennedy, A. (2008). A multiple regression analysis of syntactic and semantic influences in reading normal text. *Journal of Eye Movement Research*, *2*(4), 1–11. Retrieved from http://www.jemr.org/online/2/1/4

Pynte, J., New, B., & Kennedy, A. (2008). On-line contextual influences during reading normal text: A multiple-regression analysis. *Vision Research*, *48*, 2172–2183. doi:10.1016/j.visres.2008.12.016

Rayner, K. (1978). Eye movements in reading and information processing. *Psychological Bulletin*, *85*(3), 618–60. doi:10.1080/13803395.2011.639298

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*(3), 372–422. doi:10.1037/0033-2909.124.3.372

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, *105*(1), 125–157. doi:10.1037/0033-295X.105.1.125

Sanders, T., & Schilperoord, J. (2006). Text Structure as a Window on the Cognition of Writing: How Text Analysis Provides Insights in Writing Products and Writing Processes. In C. A. Macarthur, S. Graham, & J. Fitzgerald (Eds.), *Handbook of Writing Research* (pp. 386–401). New York: Guildford Press.

Schad, D. J., Nuthmann, A., & Engbert, R. (2012). Your mind wanders weakly, your mind wanders deeply: objective measures reveal mindless reading at different levels. *Cognition*, *125*(2), 179–94. doi:10.1016/j.cognition.2012.07.004

Schnitzer, B. S., & Kowler, E. (2006). Eye movements during multiple readings of the same text. *Vision Research*, *46*(10), 1611–32. doi:10.1016/j.visres.2005.09.023

Smith, M., & Wheeldon, L. (1999). High level processing scope in spoken sentence production. *Cognition*, *73*(3), 205–246. doi:10.1016/S0010-0277(99)00053-0

Smith, N. J., & Levy, R. (2013). The effect of word predictability on reading time is logarithmic. *Cognition*, *128*(3), 302–19. doi:10.1016/j.cognition.2013.02.013

Starr, M. S., & Rayner, K. (2001). Eye movements during reading: some current controversies. *Trends in Cognitive Sciences*, *5*(4), 156–163. doi:10.1016/S1364-6613(00)01619-3

Strömqvist, S., & Karlsson, H. (2000). *Scriptlog for windows - user's manual*. Lund: Department of Linguistics, Lund University and Centre for Reading Research, University College of Stavanger.

Torrance, M. (2015). Understanding Planning in Text Production. In C. MacArthur, S. Graham, & J. Fitzgerald (Eds.), *Handbook of Writing Research* (2nd Editio.). New York: Guildford Press.

Torrance, M., & Nottbusch, G. (2012). Written Production of Single Words and Simple Sentences. In V. Berninger (Ed.), *Past, Present, and Future Contributions of Cognitive Writing Research to Cognitive Psychology* (pp. 403–422). New York: Taylor Francis.

Van Waes, L., Leijten, M., & Quinlan, T. (2010). Reading during sentence composing and error correction: A multilevel analysis of the influences of task complexity. *Reading and Writing*, *23*(7), 803–834. doi:10.1007/s11145-009-9190-x

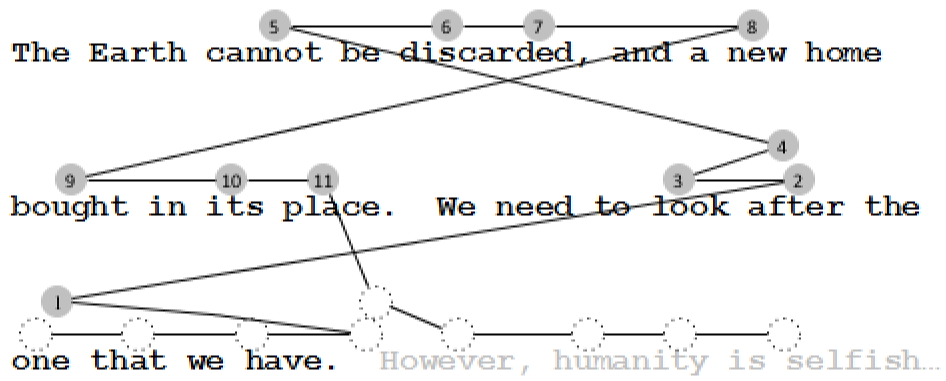
Wengelin, Å. (2006). Examining Pauses in Writing: Theory, Methods and Empirical Data. In K. Sullivan & E. Lindgren (Eds.), *Computer Key-Stroke Logging and Writing* (pp. 107–130). Amsterdam: Elsevier.

Wengelin, Å., Torrance, M., Holmqvist, K., Simpson, S., Galbraith, D., Johansson, V., & Johansson, R. (2009). Combined eyetracking and keystroke-logging methods for studying cognitive processes in text production. *Behavior Research Methods*, *41*(2), 337–351. doi:10.3758/BRM.41.2.337

White, S. (2008). Eye movement control during reading: Effects of word frequency and orthographic familiarity. *Journal of Experimental Psychology-Human Perception and Performance*, *34*(1), 205–223. doi:10.1037/0096-1523.34.1.205

Figures and Tables

Figure 1. Example of eye movement in the Composition-Writing task, Experiment 2, to illustrate coding.



Note. This sequence shows a participant writing up to a sentence-initial position then looking back. Filled circles represent fixations included in analyses. Fixations 1 to 4 are local and not part of a reading sequence. Fixations 5 to 11 are distal and are part of a reading sequence. Fixations tended to be directly on the text but are show above for clarity. Empty circles represent fixations occurring concurrently with typing, on the word currently being typed. These were not analysed. Greyed text represents text written after the numbered sequence of fixations. Line length has been shorted for ease of illustration.

Table 1. Eye movement in already-written text, by location of last-typed character, for the Composition Writing task. 95% confidence intervals in parenthesis.

	Mid-Sentence			At sentence boundary		
	Within word *b^o^y*	Word terminal *The^ boy^*	Word initial *The ^boy*	Sentence terminal *swam^. Then*	After terminal punctuation *swam.^ Then*	Sentence initial *swam. ^Then*
Probability of looking back	.05 (.03, .07)	.07 (.05, .11)**	.12 (.08, .17)**	.31 (.19, .45)**	.33 (.21, .47)**	.45 (.32, .60)**
Mean total number of fixations	1.8 (.8, 2.8)	2.4 (1.4, 3.4)	3.5 (2.6, 4.5)**	4.2 (2.3, 6.0)*	3.3 (1.6, 5.0)	10.6 (9.0, 12.1)**
Probability that looking back includes one or more reading sequences	.01 (.00, .03)	.06 (.03, .11)**	.13 (.07, .22)**	.07 (.01, .22)*	.12 (.03, .30)**	.29 (.14, .50)**
Mean first fixation duration	248 (218, 277)	227 (194, 260)	234 (203, 264)	188 (114, 262)	226 (159, 294)	249 (189, 309)
Mean gaze duration	319 (272, 364)	292 (240, 344)	287 (238, 335)	224 (104, 344)	299 (189, 408)	303 (206, 401)
Mean distance of fixations from cursor.	8.5 (5.8, 12.4)	8.1 (5.5, 11.8)	6.2 (4.2, 9.0)**	8.6 (5.0, 14.8)	13.0 (7.7, 21.7)*	10.6 (6.6, 17.2)

Note: ^ in examples indicates location of text boundary. Parameter estimates from linear mixed effects models. * $p < .05$, ** $p < .005$, for test of the null hypothesis of no difference from the within-word value.

Table 2. Proportion of within-text fixation runs by task, location relative to last-typed word (distal or local), and whether or not fixations were part of a sustained reading sequence. Standard deviation in parenthesis.

Task	*Part of a reading sequence*		*Not part of a reading sequence*	
	Distal	*Local*	*Distal*	*Local*
Composition-writing	20% (8%)	17% (9%)	33% (19%)	29% (11%)
Read-and-Edit	39% (9%)	17% (8%)	32% (10%)	12% (5%)

Table 3. Log likelihood and χ^2 change test results for mixed effects models exploring task, reading sequence, distal / local, word length and word frequency effects.

Model	First fixation duration		Gaze duration		Fixations per run	
	LL	$\Delta\chi^2$	LL	$\Delta\chi^2$	LL	$\Delta\chi^2$
0. Intercept only	-47809		-52035		-6473	
1. Model 0 plus main and interaction effects of task, reading-sequence vs. not-reading-sequence, & distal vs. local	-47806	5.6 ns	-52012	46**	-6419	107**
2. Model 1 plus effects of word frequency estimated for each cell of the task x reading-sequence x distal/local interaction	-47789	35**	-51988	49**	-6393	51**
3. Model 2 plus effects of word length estimated for each cell of the task x reading-sequence x distal/local interaction	-47786	5.3 ns	-51938	98**	-6290	207**

Note. Zero model (Model 1) has 7734 degrees of freedom. χ^2 change is relative to previous model. Model 2 vs. Model 1, df = 7. Model 3 vs. Model 2 and Model 4 vs. Model 3, df = 8. ** $p < .001$, ns $p > .05$

Table 4. Estimated means for eye-movement measures during Composition Writing by fixation location relative to the last-type character (distal or local) and whether or not fixations were part of a sustained reading sequence. Standard error in parenthesis. Values for distal reading sequences in the Read-and-Edit condition shown for comparison.

	Part of a reading sequence		*Not part of a reading sequence*		*Read-and-Edit task, distal reading sequences*
	Distal	*Local*	*Distal*	*Local*	
Mean first fixation duration (ms)	208 (5.5)	220 (5.6)	214 (5.3)	220 (5.3)	215 (5.8)
Mean gaze duration (ms)	241 (9.3)**	256 (9.5)*	239 (8.9)**	264 (8.9)	275 (9.7)
Mean fixations per run	1.17 (.024)**	1.17 (.025)**	1.10 (.023)**	1.17 (.023)**	1.31 (.024)

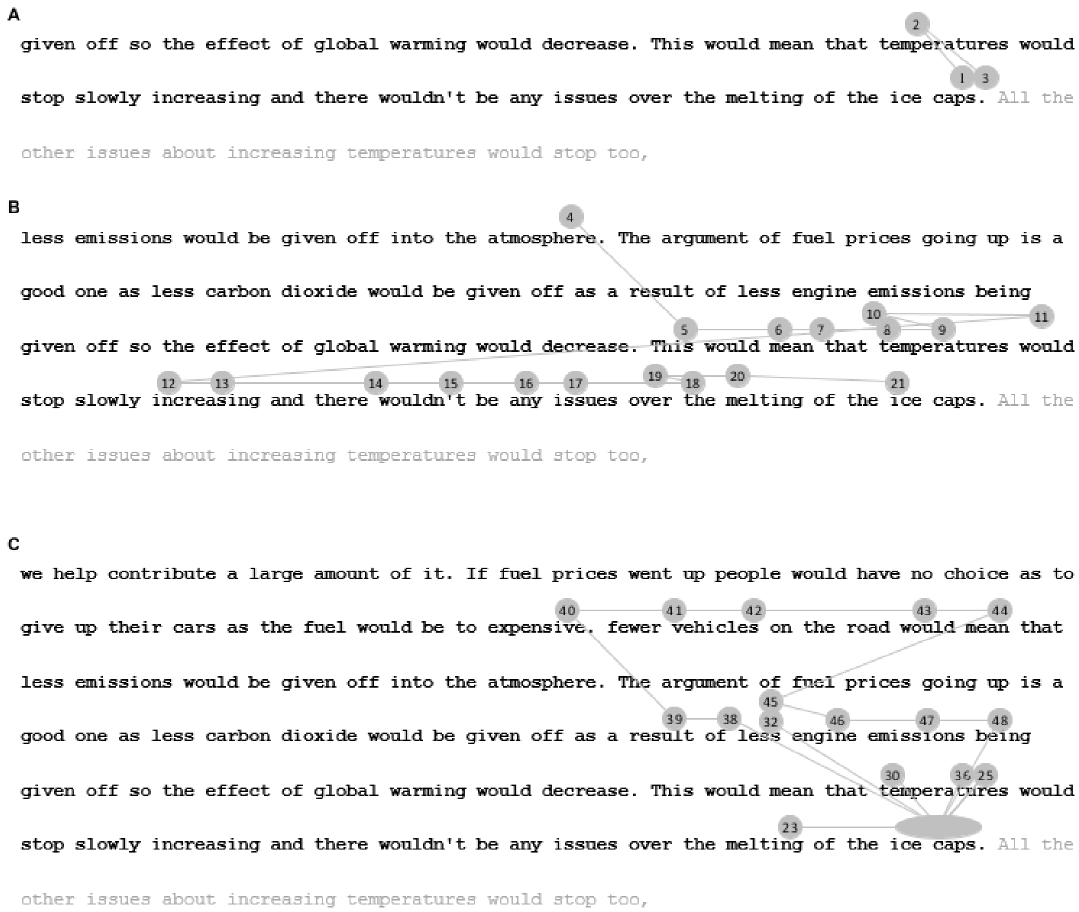
Note. Values are parameter estimates from the best-fit linear mixed-effects model. Statistical significance is for difference relative to fixations in distal reading-sequences during the Read-and-Edit task, as the condition best representing "normal" reading. * $p < .05$, ** $p < .005$.

Table 5. Effects of the frequency and length of the fixated word on eye-movement measures during Composition Writing, by task, fixation location relative to last-typed word (distal or local), and whether or not fixations were part of a sustained reading sequence. Standard error in parenthesis. Values for distal reading sequences in the Read-and-Edit condition shown for comparison.

		Part of a reading sequence		*Not part of a reading sequence*		*Read-and-Edit task, distal reading sequences*
		Distal	*Local*	*Distal*	*Local*	
Word Frequency	First fixation duration	5.8 (5.5)	-.5 (6.6)	8.1 (4.2)	5.5 (5.0)	-11.1 (3.9)**
	Gaze duration	6.2 (9.5)	-9.3 (11.4)	10.1 (8.0)	-3.6 (8.5)	-18.2 (6.7)*
	Fixations per run	.00 (.026)	-.02 (.031)	.01 (.022)	-.03 (.023)	-.02 (.018)
Word Length	First fixation duration	1.8 (2.1)	-2.2 (2.5)	2.1 (1.8)	-.2 (1.9)	-.2 (1.3)
	Gaze duration	6.9 (3.6)	2.5 (4.2)	10.9 (3.1)**	4.9 (3.2)	10.9 (2.2)**
	Fixations per run	.03 (.010)**	.03 (.012)*	.02 (.009)*	.02 (.009)*	.05 (.006)**

Note. Parameter estimates from best-fit linear mixed-effects model. * $p < .05$, ** $p < .005$, for test of the null hypothesis that there is no effect.

Figure 2. Example of fixations associated with looking back into already-produced text during a sentence-boundary pause in typing.



Note. Figure shows the first 48 fixations, split across 3 panels for clarity, from a sequence of 241 that occurred during a typing-free pause prior to starting the new sentence (shown in grey). Fixations 22, 24, 26-29, 31, 33-37 (panel C) all on “ice caps. ”. For clarity fixations are shown above rather than on the text. Horizontal location is precise.