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The time-course of recovery from interruption during reading: Eye movement evidence for the role of interruption lag and spatial memory

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Two experiments examined how interruptions impact reading and how interruption lags and the reader's spatial memory affect the recovery from such interruptions. Participants read paragraphs of text and were interrupted unpredictably by a spoken news story while their eye movements were monitored. Time made available for consolidation prior to responding to the interruption did not aid reading resumption. However, providing readers with a visual cue that indicated the interruption location did aid task resumption substantially in Experiment 2. Taken together, the findings show that the recovery from interruptions during reading draws on spatial memory resources and can be aided by processes that support spatial memory. Practical implications are discussed.

Keywords: Reading; Interruption; Eye movement; Memory; Comprehension.

Interruptions are a common aspect of life in societies like ours where we are surrounded by sources that provide information continuously and where it is tempting to quickly check the latest news and updates. Laboratory studies investigating the impact of interruptions in tasks such as problem solving (Hodgetts & Jones, 2006a), reading (Glanzer, Dorfman, & Kaplan, 1981), and visual search (Shen & Jiang, 2006) have demonstrated the adverse effects of interruptions, and field studies have corroborated such findings in various work-related environments (McFarlane & Latorella, 2002). As such, identifying ways to alleviate the deleterious effects of interruptions is an issue of high practical importance (cf. Bailey & Konstan, 2006). Furthermore, understanding the cognitive processes involved in recovering from interruptions in reading has important implications for theories of memory because they address the interaction of short- and long-term goals as well as issues of consolidation and storage (Ericsson & Kintsch, 1995).

Our theoretical framework and predictions are informed by both the *memory for goals model* (Altmann & Trafton, 2002, 2007) and the *theory of long-term working memory* (LTWM; Ericsson & Kintsch, 1995), two models that have become particularly prominent in the interruption

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literature. The memory for goals model is a general model of interruption effects and was originally developed in the area of problem solving. The LTWM theory, on the other hand, was initially developed to account for memory processes in reading and expert performance. Relying on these theoretical frameworks, the present study sought to make use of the advantages of eye tracking to better understand the influence of interruptions during reading. More precisely, we focused on two specific issues. The first concerns whether reading resumption is aided by the presence of an *interruption lag*—an interruption lag being defined as the time between a person becoming aware of an impending interruption (e.g., a telephone ringing) and engaging with the interruption (e.g., answering the phone; Trafton, Altmann, Brock, & Mintz, 2003). According to the memory for goals model, individuals can prepare themselves during an interruption lag to more easily resume the primary task following the interruption. Interruption lag effects have been reported in previous studies unrelated to reading (Trafton et al., 2003), but never in the reading research literature, and the current work seeks to explore the role of interruption lags in the recovery process. The second issue addressed is concerned with whether spatial memory plays a role in recovering from interruptions during reading. Recent research in the context of nonreading tasks (e.g., a typing task; Ratwani & Trafton, 2008) suggests that spatial memory may indeed play an important role in task resumption, but no studies have investigated this issue in the context of a reading task. Neither of the two models mentioned currently accounts for spatial memory processes.

The memory for goals model is based on the construct of activation as interpreted in the adaptive character of thought–rational (ACT–R) cognitive theory (Anderson & Lebiere, 1998) and posits that the most active goal at a given time directs cognition. When a primary task is interrupted, the corresponding goal is suspended, and the activation level of this goal decays rapidly, so that the activation level is negligible after an interruption as brief as 30 s (assuming that the interrupting task engages the cognitive resources that would otherwise be used to rehearse such information). Upon resumption, the time needed to resume the activity reflects the process of retrieving the suspended goal. The lower the activation level of the suspended goal, the less easily that goal can be retrieved. Two fundamental processes, priming and strengthening, can facilitate goal retrieval upon resumption. First, the suspended goal can be *primed* with a goal-linked cue that is available immediately prior to an interruption and which is also made available upon task resumption. When such cues are attended to upon resumption, they spread activation to the goal with which they are associated, and goal retrieval is facilitated. Second, the basic activation level of a to-be-suspended goal, and the link between environmental cues and the associated goal, can be *strengthened* before the interruption. The interruption lag is the ideal window of opportunity for this strengthening process. Preparation during the interruption lag can facilitate subsequent goal retrieval upon resumption by consolidating existing cue–goal associations and by building up the activation of the goal itself. A standard measure of ease of task resumption is adopted: the *resumption lag*. The resumption lag is defined as the time between the interruption offset and the first subsequent task-relevant response (see Altmann & Trafton, 2002). The assumptions of the memory for goals model are supported by empirical findings across a range of tasks unrelated to reading, such as problem solving (Altmann & Trafton, 2002; Hodgetts & Jones, 2006a, 2006b), tactical decision making (Altmann & Trafton, 2004, 2007; Trafton, Altmann, & Brock, 2005; Trafton et al., 2003), and video-cassette recorder (VCR) programming (Monk, Trafton, & Boehm-Davis, 2008).

Across a series of experiments, Glanzer and collaborators (B. Fischer & Glanzer, 1986; Glanzer et al., 1981; Glanzer, Fisher, & Dorfman, 1984) investigated specifically the effects of interruptions on the reading process. In their experiments, participants were presented with a text of a few sentences; these were displayed one sentence at a time using a self-paced reading method. The sentences were presented in either a noninterrupted or an interrupted format, with the interruptions introduced as arithmetic or unrelated reading tasks initiated in between two sentences of the text. Glanzer and collaborators found that the reading time of the first sentence following the interruption was inflated relative to the uninterrupted condition, and that the duration and demand level of the interruption seemed to influence subsequent reading time. Specifically, short addition problems lasting 10 s increased reading time by approximately 350 ms (Glanzer et al., 1981, Experiment 2a), whilst demanding numerical tasks, such as digit recall, lasting for 30 s increased reading times by approximately 1.5 s (B. Fischer & Glanzer, 1986, Experiments 2, 3, and 4). It must be noted however, that when the interruption comprised reading of unrelated sentences, there was no comparable difference in reading times between a 10-s and a 30-s interruption (315 ms vs. 355 ms respectively; Glanzer et al., 1984, Experiments 1 and 3). In addition, Glanzer and colleagues showed that the increase in reading time disappeared when the readers were presented with the last one or two sentences that preceded the interruption before reading the postinterruption sentences. In a similar vein, another study (Lorch, 1993) showed that the increases in reading time disappeared when the reader was reminded of the general topic of the text by means of a cue word before reading the postinterruption sentences. This demonstrates that words can be efficient retrieval cues in interrupted reading. Finally, Glanzer and collaborators found no effect of interruptions on overall comprehension, even when participants were faced with longer and more demanding interruptions. Oulasvirta and Saariluoma (2006) recently confirmed these findings, showing that a 30-s interruption does not hamper reading comprehension regardless of its intensity or difficulty, and they noted that they are at odds with the memory for goals model if it is to be applied to a reading context. According to the model, the activation level of the primary-task representations should have been negligible after a demanding 30-s interruption, leading to irreparable memory loss. On the contrary, they are consistent with the basic assumptions of the LTWM theoretical framework developed by Ericsson and Kintsch (1995; detailed in the following paragraph).

In contrast to the memory for goals model, the LTWM theoretical framework posits that, during normal reading, information can be rapidly stored in and retrieved from long-term memory, so that long-term memory serves as an extended working memory. Information about text previously read and stored in long-term memory is kept accessible by means of retrieval cues stored in short-term working memory. The findings reported by previous interruption studies in relation to reading support the LTWM account for the following reason. Although interruptions disrupt the information stored in short-term working memory during reading, they do not appear to cause an irretrievable loss of information, as the overall comprehension of the text is not impaired (see B. Fischer & Glanzer, 1986; Glanzer et al., 1981; Oulasvirta and Saariluoma, 2006). Thus, information seems to be rapidly and accurately consolidated into long-term memory whilst reading. According to Ericsson and Kintsch (1995), when readers resume reading the text after the interruption, the novel information serves as a retrieval cue to information about text previously read and stored in long-term memory. They also argued that the increased reading times that are observed in these studies reflect these retrieval operations. This interpretation was further corroborated by Oulasvirta and Saariluoma (2006), who showed that interruptions do not hamper comprehension unless the interface drastically limits the reading time so that the readers do not have enough time to store information in long-term memory.

In relation to the assumptions of these theoretical models, the present study tapped into two specific research issues. First, we examined whether the time taken to resume an interrupted reading task is aided by the presence of an interruption lag when the primary text was unavailable. According to the memory for goals model, individuals can prepare themselves during an interruption lag, consolidating information about text just read into memory, to more easily resume the primary task after the interruption. Therefore, Experiments 1 and 2 examined this issue by manipulating the presence of a 3-s and an 8-s interruption lag, respectively. Second, we examined the role of spatial memory in recovering from interruptions occurring during reading. We hypothesize that recovery from interruption involves two cognitive processes: (a) reinstating previously read information in memory, and (b) searching for the point in the text where the interruption occurred. In Experiment 2, we examined the latter hypothesis relating to spatial memory, by manipulating the presence of a visual cue (i.e., a highlighted word) on reading resumption indicating the point in the text where the interruption occurred. An eye movement paradigm was used in both experiments. Interruptions were launched when the gaze of the readers arrived at a predefined target word, and the readers were free to progress through the text as they wished before and after the interruption. We expected this paradigm to yield a more accurate account of the way readers recover from interruptions than the sentence-by-sentence procedure used in previous studies.

EXPERIMENT 1

The primary goal of Experiment 1 was to investigate whether reading resumption is aided by the presence of an interruption lag. Because we used an eye movement paradigm, Experiment 1 also provided the opportunity to gain more insight into the way readers recover from interruptions in a normal reading situation (as opposed to a sentence-by-sentence reading situation). Regarding the first goal, according to the memory for goals model, an interruption lag provides the opportunity to consolidate the existing representation in memory and to encode associated environmental cues that will serve as retrieval cues upon task resumption. Previous studies have confirmed that the presence of an interruption lag can aid task resumption outside of a reading context, but the evidence is rather scarce. These studies used either a tactical decision making task (Altmann & Trafton, 2004, 2007; Trafton et al., 2003) or a problem solving task (the Tower of London; Hodgetts & Jones, 2006a) where the availability of primary task information during the interruption lag was also frequently manipulated; the display either was replaced by a blank screen or remained visible (though in a "frozen" state; i.e., interaction with the display was disabled in both conditions). The results generally suggest that an interruption lag as brief as 2 s can aid task resumption, especially if primary task information is still available during the interruption lag. However, evidence has also been provided indicating that an interruption lag can be beneficial when primary task information is removed during the interruption lag (Altmann & Trafton, 2007). In the present experiment, we investigated whether the adverse effects of interruptions can be mitigated by the presence of a 3-s interruption lag whilst the text was removed from sight. We chose to remove the text during the interruption lag for two reasons: (a) to control the exact point where the reader stopped reading—that is, to prevent the reader from continuing on in text reading or returning over previously read text, and (b) to induce a disruptive form of interruption, where immediate visual attention is drawn away from the text being read. This type of interruption is representative of real-life interruptions where text being read is replaced/covered by a reminder or error pop-up message, or when visual attention is directed elsewhere away from the text (e.g., towards the office door if there is a loud unexpected knock). We also considered alternative methods for the interruption lag, including freezing the text—that is, keeping the text on the screen during the interruption lag—and isolating the text just read during the interruption lag—that is, removing the text before and after the current sentence. However, it has been argued that such methods are "unnatural" in relation to user interfaces (Oulasvirta & Saariluoma, 2006, p. 957) and so were not adopted in the present study.

In the experiment, participants read paragraphs whilst their eye movements were monitored. Three categories of trials were run: interruption trials, delayed interruption trials, and no-interruption trials. In the interruption trials, when the gaze of the reader arrived on a predefined word, the text disappeared, and a 60-s audio story was played. At the offset of the audio file, after having commented on the audio story over a few seconds, the participant was presented once again with the text to resume reading. In the delayed interruption trials, the procedure was identical to the interruption trials, except that when the gaze of the reader arrived at a predefined target word, and the text disappeared, it was not until 3 s had elapsed (i.e., after the interruption lag) that the audio story was started. In the no-interruption trials, the text did not disappear when the gaze of the reader alighted on the predefined target word (but a virtual mark was added to the data in order to allow comparisons with the other trials). The eye-tracking methodology permitted us to implement the established measure of task resumption used in the interruption literature: the resumption lag. We reasoned that the first "task-relevant response" in reading resumption would be processing novel text information. Thus, we defined the resumption lag in our paradigm as the time spent rereading the preinterruption text portion upon reading resumption.

We made two main predictions regarding our results. First, in line with the LTWM theory, we expected that information about previously read text would be safeguarded in long-term memory before the interruption. As such, even if our interruptions were longer than interruptions manipulated in previous interrupted-reading studies (60 s in our study as opposed to a maximum of 30 s in earlier studies), readers were expected to not have to reread the entire preinterruption text portion upon resumption before processing novel text. However, we expected that the readers would reread the preinterruption text portion to reinstate previously read information in memory and to search for the point in the text where the interruption occurred (the two main cognitive processes we assumed to be involved in recovering from interruptions). Second, in line with the memory for goals model, we expected that readers would use the interruption lag to consolidate the representation of the text in memory. Accordingly, we predicted the time spent rereading the preinterruption text portion upon resumption to be shorter in the delayed interruption trials than in the interruption trials.

Method

Participants

Thirty-eight participants were recruited from the University of Kent and participated in the study in exchange for either £5 payment or 4 study credits. All participants were native English speakers with normal or corrected-to-normal vision. Six participants had to be excluded due to poor calibration; analyses were therefore based on a sample of 32 participants. The final sample consisted of 18 women and 14 men with a mean age of 22.06 years ($SD = 7.02$).

Apparatus

Eye movements were recorded using an EyeLink 1000 desktop mounted SR Research eyetracker (SR Research, 2011) and were sampled at a frequency of 1000 Hz. Only the right eye was tracked, and the participant's head was kept immobile with the use of a chin and head rest throughout the experiment. A 19-inch CRT screen with a screen resolution of $1{,}024 \times 768$ pixels was used to present stimuli at a distance of 60 cm from the participant. Participants' eye movements were calibrated through a nine-point calibration process, which covered all the main central and peripheral aspects of the screen.

Materials

Twenty-four paragraphs, chosen from a number of different textbooks, biographical texts, and fiction texts, were used in the reading task (see Appendix). The paragraphs were selected such that they did not require any domain-specific knowledge and were easy to understand on first reading. All paragraphs were presented in double-spaced format and were arranged so that one screen contained 14 lines of text. On average, paragraphs were 158.35 ($SD = 6.80$) words in length. For each paragraph, a target word on the seventh line was chosen; interruptions were initiated when the participants' eyes reached these target words. Target words were chosen randomly within the seventh line with the exclusion of the two words at the extremes of the line, which were never selected and were fixed for each paragraph across participants. The target words were the first word of a sentence only twice across the 24 paragraphs, with the remaining interruptions occurring during sentence processing, rather than in between two sentences. Across previous interruption studies, interruptions were always initiated at the juncture between two sentences. Such interruptions have been shown to be less disruptive than those occurring midsentence (see McNamara & Kintsch, 1996). Furthermore, interruptions occurring during sentence processing are more likely to be representative of interruptions occurring in natural settings, given that the chance of an interruptions occurring exactly at the point between two sentences is unlikely.

One multiple-choice comprehension question was created for each paragraph. The questions were based on facts presented within the paragraphs, and each question was presented with two possible answers. The answers to each question could be considered perfectly feasible if the paragraph had not been read previously.

Interruptions took the form of sixteen 60-s audio news stories. The news stories were taken from news websites in the UK (e.g., BBC news, Guardian Online, and Times Online). All of the stories were read into a Dictaphone in the same male voice; these were converted into digital .wav files for the experiment.

Procedure

Initially participants' eye movements were calibrated. After being introduced to the task and example materials during a familiarization phase, participants read the 24 paragraphs. Participants were instructed to read the paragraphs for comprehension and were made aware that they would be asked questions regarding the content of the paragraphs after reading each paragraph. Following individual paragraphs, participants were immediately presented with a comprehension question relating to the paragraph they had just read, to which they responded by using the keyboard. Participants then rated the difficulty of the paragraph on a seven-point scale (1 being very easy, 7 being very difficult).

Participants read the paragraphs while their eye movements were monitored, and one third of the paragraphs were read in an interruption condition, one third in a delayed interruption condition, and one third in a no interruption condition. In the interruption trials, when the gaze of the reader alighted on the predefined target word, the text disappeared, and a 60-s audio story was played via headphones that the participant was wearing. At the offset of the audio file, a blue box appeared on the computer screen, and the participant was to describe briefly the story in a sentence to the experimenter. The experimenter ensured that the description phase would never exceed a very brief period of time (approximately 5–7 s maximum) by stopping participants after only a short description had been given. The participant was then presented with a cross to fixate at the top of the screen and then returned to the paragraph to resume reading. In the delayed interruption trials, the procedure was identical to that of the interruption trials, except that when the gaze of the reader alighted on the predefined target word, and the text disappeared, it was not until 3 s had elapsed (i.e., the interruption lag) that the audio story started. Three seconds was chosen in line with previous interruption lag research (Hodgetts & Jones, 2006b). In the no interruption trials, the text did not disappear when the gaze of the reader reached the predefined target word but a virtual mark was added to the data in order to allow systematic comparisons with the other trials (pre- and postinterruption periods were distinguished for all trials, see Results section). During the familiarization phase of the experiment, the participants were made aware that the screen might go blank during reading and that they might hear an audio story through headphones and be asked to briefly describe the audio story in a sentence afterwards. They were informed that following the story they were to finish reading the text. They were also advised that they were free to resume reading the texts as they wished, as long as they were able to answer the comprehension question afterwards.

For each participant, the order of paragraphs was randomized, and the assignment of interruption type (interruption, delayed interruption, and no interruption) was also randomized.

Analyses

A series of repeated measure analyses of variance (ANOVAs) were conducted for each dependent measure. These analyses used the eye movement measures, difficulty ratings, and comprehension scores as dependent variables and interruption type (interruption, delayed interruption, no interruption) as the within-subject independent variable. Global eye movement measures were used, which reflect higher level dimensions of the reading process, such as semantic integration (see Rayner, 1998; Reichle, Pollatsek, Fisher, & Rayner, 1998); these were: reading time (the summed duration of fixations in seconds); the number of fixations (the summed number of fixations across text); mean fixation duration (the mean duration of the first-pass first fixations in ms); the probability of regression; and the mean length of saccades (in characters, 1 character = 0.94 degrees of visual angle). To decrease the risk for Type I error across analyses where multiple eye movement measures were used, Bonferroni corrections were applied; the resulting alpha for these analyses was .01. Similarly, in the case of a significant ANOVA and where multiple comparisons were needed, additional post hoc analyses using Bonferroni correction were computed to identify the source of the effect. In line with our theoretical framework, we were particularly interested in two general types of comparison: the comparison between the interruption and no interruption conditions, and the comparison between the interruption and delayed interruption conditions.

Three main sets of analyses were conducted on the eye movement measures. We distinguished the pre- and postinterruption periods, depending on whether the eyes of the reader had or had not already landed on the predefined target word (the word triggering an interruption in the interruption and delayed interruption trials). In addition, we distinguished the pre- and postinterruption text—that is, the text located before the target word and the text located after the target word. Accordingly, the first set of analyses concerned the initial reading of the preinterruption text, before the reader had reached the target word. These were conducted to ensure there were no differences in interruption conditions prior to the interruptions and also so that any eye movement over this portion of text following an interruption could be compared with normal reading of this portion of text prior to interruptions. The second set of analyses related to the preinterruption text after the reader had reached the target word (and triggered an interruption in the interruption and delayed interruption trials). The third set of analyses concerned the postinterruption text (and consequently the postinterruption period).

Additional analyses were conducted to examine the possibility that participants were trying to predict and compensate for an upcoming interruption by slowing down their reading. For these analyses, we examined eye movement measures of mean fixation duration and regression probability aggregated across lines 4 and 5 (mid preinterruption text), and across lines 6 and 7 (immediately prior to the interruption), where longer fixations and more regressions on the latter lines would indicate the slowing down of reading. For this analysis, both line proximity (lines 4 and 5 vs. lines 6 and 7) and interruption type were used as within-subject independent variables and the fixation duration and regression probability as the dependent variables. These analyses were subject to Bonferroni correction to reduce the risk of Type I error; the resulting alpha set for these analyses was .025.

Each trial was checked to see whether the eyes of the reader had reached the target word at an appropriate time. Only trials in which the target word had been reached after the previous lines had been covered, and in which the target word was reached prior to the postinterruption text being read, were included in the final analyses. These stringent criteria led to 10% of erroneous data being removed but were necessary to avoid trials with a premature delivery of the interruption text to be included. Analyses were conducted on the remaining data. Further outliers in the remaining eye movement data were identified by calculating the residual z scores. Any data point that had a relative z score greater than 2.5 or less than –2.5 was removed from the data.

Results and discussion

The first set of analyses concerned the initial reading of the preinterruption text, before the reader had reached the target word. The data are presented in Table 1. Analyses revealed no significant effects of interruption type for all dependent measures—namely, reading time, number of fixations, mean fixation duration, regression probability, and mean saccade length (all ps $> .05$). This was not surprising, as interruption, delayed interruption, and no interruption trials were completely unpredictable. Participants on average took 14.06 s to read the preinterruption text, made 58.71 fixations, and had a mean fixation duration of 208 ms, a regression probability of around 7%, and a saccade length of 9.23 characters (aggregated across all interruption types). Within this preinterruption period, we also examined whether there was any evidence of readers anticipating an upcoming interruption and slowing down to prepare for it accordingly. There was no evidence of such anticipation, with participants having similar mean fixation durations on lines 4 and 5 ($M = 213$ ms, $SE = 4$) as on lines 6 and 7, which were closer to the interruption point ($M = 211$ ms, $SE = 4$, $p > .1$ for all main effects and interactions). There was a significant main effect of line proximity for the frequency of regression, $F(1,\ 31) = 284.22$, $p < .001$, $\eta_p^2 = .90$, with more regressions initiated from words on lines 4 and 5 ($M = .15$, $SE = .01$), than from words on lines 6 and 7 ($M = .12$, $SE = .007$). However, this effect is not indicative of a slowing down of reading, as one would expect more regressions, rather than fewer, if participants were to read more carefully in anticipation of an interruption.

The second set of analyses concerned the rereading of the preinterruption text following the interruption. Analyses revealed a significant effect of interruption type for reading time, $F(2,\ 62) = 64.23$, $p < .001$, $\eta_p^2 = .67$. Consistent with our expectations, the readers spent some time rereading the preinterruption text upon resumption in the interruption trials. They spent on average 4.85 s rereading the preinterruption text in these

Table 1. *Eye movement results for the pre- and postinterruption text (space-wise) and for the pre- and postinterruption periods (time-wise) in Experiment 1*

			Reading Time (s)		*Number of Fixations*		*Mean Fixation Duration (ms)*		*Regression Probability*		*Mean saccade length (char.)*	
Period	*Text*	*Int. Type*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Preinterruption period	Preinterruption text	N.Int	14.32	*2.63*	59.58	*7.94*	210	*22*	0.08	*0.03*	9.10	*1.38*
		D.Int	13.91	*2.66*	58.19	*8.40*	208	*22*	0.07	*0.03*	9.32	*1.44*
		Int.	13.96	*2.66*	58.36	*7.79*	207	*23*	0.07	*0.03*	9.28	*1.48*
Postinterruption period	Preinterruption text	N.Int	1.21	*0.59*	5.44	*2.44*	172	*28*	0.01	*0.008*	10.21	*2.85*
		D.Int	4.98	*2.24*	25.45	*10.77*	190	*23*	0.06	*0.03*	11.25	*2.05*
		Int.	4.71	*2.04*	23.87	*9.59*	190	*21*	0.06	*0.03*	11.36	*2.40*
	Postinterruption text	N.Int	14.77	*3.16*	68.75	*11.99*	214	*21*	0.15	*0.06*	9.58	*1.68*
		D.Int	13.84	*3.49*	65.87	*13.94*	207	*23*	0.15	*0.06*	10.13	*2.05*
		Int.	13.74	*3.04*	66.20	*11.32*	208	*22*	0.16	*0.05*	10.20	*2.06*

Note: Int. Type = interruption type; N.int = no interruption; D.Int = delayed interruption; Int = interruption. Reading time = the summed duration of fixations in seconds. Number of fixations = the summed number of fixations across text. Mean fixation duration = the mean duration of the first-pass first fixations. Regression probability = the probability of regression from words within the portion of text. For mean length of saccades, 1 char. (character) = 0.94 degrees of visual angle.

conditions, which contrasted clearly with the mean 1.21 s spent rereading the preinterruption text after having reached the target word in the no interruption trials ($p < .001$; in the latter trials, rereading was due to incidental regressions often occurring during reading). In addition, the results showed that the readers did not reread the entire preinterruption text in the interruption trials. In contrast to the first set of analyses, where participants spent around 14 s reading the same portion of text before the interruption, one can note that the resumption lags of the readers were remarkably short (i.e., a few seconds, if incidental regressions from postinterruption text are excluded). However, in contrast to our predictions, readers did not seem to benefit from the interruption lag, as there was no significant difference between the interruption and delayed interruption conditions for the reading time measure (4.71 s vs. 4.98 s). With respect to the other eye movement measures, there were significant effects of interruption type for the number of fixations, $F(2, 62) = 81.89$, $p < .001$, $\eta_p^2 = .73$, fixation duration, $F(2, 62) = 10.91$, $p < .001$, $\eta_p^2 = .26$, regression probability, $F(2, 62) = 65.51$, $p < .001$, $\eta_p^2 = .68$, and saccade length, $F(2, 62) = 5.81$, $p < .01$, $\eta_p^2 = .16$. Post hoc analysis indicated that readers made more fixations (23.87 vs. 5.44), made longer fixations (190 ms vs. 172 ms), had higher regression probability rates (6% vs. 1%), and made larger saccades (11.36 vs. 10.21) in the interruption condition than in the no interruption condition (all ps $< .05$). In contrast, there were no significant differences between the interruption and delayed interruption conditions across these eye movement measures (all ps $> .1$).

The third set of analyses concerned the postinterruption text during the postinterruption period. Surprisingly, the effects of interruption type (i.e., significant differences between the interruption and no interruption conditions) continued onto novel text during the postinterruption period. Analyses revealed a significant effect of interruption type for reading time, $F(2, 62) = 8.27$, $p < .01$, $\eta_p^2 = .21$, mean fixation duration, $F(2, 62) = 12.55$, $p < .001$, $\eta_p^2 = .29$, and saccade length, $F(2, 62) = 7.54$, $p < .01$, $\eta_p^2 = .20$. Post hoc analysis indicated that readers spent less time reading the postinterruption text in the interruption condition than in the no interruption condition (13.74 s vs. 14.77 s, $p < .05$). In addition, they had shorter fixations (208 ms vs. 214 ms), and longer saccade length (10.20 vs. 9.58) in the interruption condition than in the no interruption condition (all ps $< .05$). There were no significant differences between the interruption and delayed interruption conditions across all eye movement measures. Altogether, these unexpected changes in eye movement behaviour suggested that the processing of the postinterruption text was somehow facilitated in the interruption trials compared to the no-interruption trials.

With regard to the comprehension scores, the analysis did not yield any significant effect of interruption type, $F(2, 62) = 2.22$, $p = .12$, $\eta_p^2 = .07$. One may wonder, however, if any ceiling effects were present as the scores were relatively high across all conditions: $M = .88$ and $SD = .12$ for the interruption condition, $M = .86$ and $SD = .15$ for the delayed interruption condition, and $M = .93$ and $SD = .11$ for the no interruption condition. In contrast, there was a significant effect of interruption type on the difficulty ratings, $F(2, 62) = 3.12$, $p = .05$, $\eta_p^2 = .09$. Post hoc analysis indicated that participants rated paragraphs as more difficult to read in the interruption condition ($M = 3.21$, $SD = 1.06$) than in the no interruption condition ($M = 2.85$, $SD = 0.95$; $p < .05$). In contrast, the participants similarly rated paragraphs as difficult to read in both the interruption and the delayed interruption conditions ($M = 3.23$, $SD = 1.02$ for the delayed interruption condition).

In sum, the results proved consistent with the predictions derived from the LTWM theory (Ericsson & Kintsch, 1995). Although our interruptions were longer than any interruptions previously manipulated in reading studies (60 s in our study compared to 30 s common in previous studies), participants did not need to reread the entire preinterruption text to successfully resume the activity. Actually, a very brief rereading duration of only a few seconds was fully sufficient. Besides this, the processing of novel text seemed even slightly facilitated compared to the no interruption condition. Altogether, these results are consistent with core assumptions of the LTWM theory: Information can be rapidly safeguarded into long-term memory during reading, so that long-term memory serves as an extended working memory. Consequently, when readers resume reading a text after an interruption, even a long and demanding one, words serve as effective cues to reinstate the existing text representation in memory (see also Oulasvirta & Saariluoma, 2006). In contrast, the results were not consistent with the predictions we derived from the memory for goals model (Altmann & Trafton, 2002, 2007) and previous interruption lag studies (e.g., Hodgetts & Jones, 2006a). The readers were not able to use the 3-s interruption lag to consolidate the existing representation of the text in memory as the resumption lags were no different in the interruption and delayed interruption trials.

EXPERIMENT 2

The primary goal of Experiment 2 was to investigate whether spatial memory plays a central role in recovering from interruptions in reading. We hypothesized previously that two cognitive processes may be involved in recovering from interruptions in reading: (a) reinstating previously read information in memory, and (b) searching for the point in the text where the interruption occurred. Whilst the former process is the primary focus of LTWM theory and the memory for goals model when accounting for the influence of interruptions, the latter process, spatial memory, may also play an important role in recovering from interruptions during reading. Recent research in the context of nonreading tasks suggests that spatial memory may indeed play an important role in task resumption (Ratwani & Trafton, 2008; see also Brudzinski, Ratwani, & Trafton, 2007; Ratwani, Andrews, McCurry, & Trafton, 2007), but no studies have investigated this issue in the context of a reading task. When resuming an interrupted reading task, readers should not only be reinstating previously read information in memory but also searching for the point in the text where the interruption occurred (second hypothesized process) so as to continue reading from this point. This is because many studies have consistently shown that spatial memory in reading (i.e., memory for word location) does exist but is very weak and short-lived (M. H. Fischer, 1999; Inhoff & Weger, 2005; Rothkopf, 1971; Therriault & Raney, 2002; Weger & Inhoff, 2007). Experiment 2 sought to explore the second hypothesized cognitive process by manipulating the presence of a visual cue (i.e., a highlighted word) at reading resumption, indicating the point in the text where the interruption occurred. The rationale of the experimental design was as follows. If searching for the point in the text where the interruption occurred is one of the central cognitive processes involved in recovering from interruptions during reading, then explicitly indicating the point in the text where the interruption occurred should aid reading resumption.

The second goal of Experiment 2 was to reexamine whether the adverse effects of interruptions can be mitigated by the presence of an interruption lag. In Experiment 1, it was possible that the readers were not able to use a 3-s interruption lag to prepare for reading resumption. In Experiment 2, we extended the duration of the interruption lag from 3 s to 8 s to ensure participants had enough time to consolidate previously read text and included specific instructions encouraging the readers to consolidate the existing text representation in memory prior to the interruption.

In Experiment 2, participants read paragraphs while their eye movements were monitored across three categories of trials; interruption trials, highlighted trials, and delayed interruption trials. The interruption trials were the same as those described for Experiment 1. In the highlighted trials, when participants were re-presented with the text after the interruption, the word that triggered the interruption was highlighted as means of a visual clue to the interruption point. In the delayed interruption trials, an interruption lag of 8 s was included prior to the initiation of the interruption to allow more time for the possible consolidation of previously read text. As with Experiment 1, the main dependent measure was the resumption lag (i.e., the time spent rereading the preinterruption text upon resumption).

We had two main predictions. First, in line with our hypotheses concerning the cognitive processes involved in recovering from interruption, we predicted that the resumption lag would be much shorter in the highlighted condition than in the interruption condition. Second, in accordance with the memory for goals model, we predicted that the resumption lag would be shorter in the delayed condition than in the interruption condition.

Method

Participants

Thirty-eight participants were recruited from the University of Kent and participated in the study in exchange for payment or study credit. All participants were native English speakers with normal or corrected-to-normal vision. Ten participants had to be excluded due to poor calibration; therefore the analyses were based on a sample of 28 participants. The final sample comprised 26 women and 2 men with a mean age of 19.54 years ($SD = 3.72$). None of the participants had participated in the first experiment.

Apparatus and materials

Apparatus and materials were the same as those in Experiment 1.

Procedure

Experiment 2 utilized the same procedure as that in Experiment 1 except that the three categories of trials that were tested were: interruption trials, highlighted trials, and delayed interruption trials (no interruption trials were not included). The interruption trials were identical to the interruption trials tested in Experiment 1. In the highlighted trials, the procedure was identical to the interruption trials with the exception that when the participants returned to the text after the interruption, the target word that triggered the interruption was highlighted in yellow for 3 s. In the delayed interruption trials, the procedure was identical to the interruption trials with the exception that when the gaze of the reader reached the target word, and the text disappeared, it was not until 8 s had elapsed (i.e., the interruption lag) that the audio story started. Eight seconds was chosen for this second interruption lag period based on previous research (Altmann & Trafton, 2004; Trafton et al., 2003). During the familiarization phase, the participants were encouraged to use the interruption-lag periods to consolidate the existing text representation in memory to prepare for resuming reading the paragraphs.

Analyses

A series of repeated measures ANOVAs were conducted for each dependent measure. These analyses used the same measures as those in Experiment 1 apart from the levels of the independent variable, where interruption type (interruption, highlighted, delayed interruption) was used as a within-subject independent variable. Bonferroni corrections were used to control for the risk of Type I errors for the main analyses using eye movement measures (resulting $\alpha = .01$). In case of a significant ANOVA, additional post hoc analyses using Bonferroni correction were systematically computed to identify the source of the effect. We were particularly interested in two comparisons: the comparison between the interruption and highlighted conditions, and the comparison between the interruption and delayed interruption conditions. The same analyses and data-removal procedures were conducted as those in Experiment 1. Specifically, only trials in which the target word had been reached after the previous lines had been covered and in which the target word was reached prior to the postinterruption text being read were included, and data-points that had a standardized residual score outside the limits of ± 2.5 were treated as outliers and were removed from the data set. These stringent criteria led to 15% of erroneous data being removed. Analyses were conducted on the remaining data.

Table 2. *Eye movement results for the pre- and postinterruption text (space-wise) and for the pre- and postinterruption periods (time-wise) in Experiment 2*

			Reading time (s)		*Number of fixations*		*Mean fixation duration (ms)*		*Regression probability*		*Mean saccade length (char.)*	
Period	*Text*	*Int. Type*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Preinterruption period	Preinterruption text	D.Int	15.88	*2.90*	61.60	*7.15*	219.00	*16.00*	0.15	*0.06*	9.14	*1.33*
		High	16.17	*3.12*	62.41	*8.12*	219.00	*18.00*	0.16	*0.06*	9.03	*1.16*
		Int.	16.63	*2.98*	62.47	*7.60*	221.00	*22.00*	0.16	*0.06*	8.98	*1.28*
Postinterruption period	Preinterruption text	D.Int	5.26	*2.26*	25.64	*11.63*	198.00	*16.00*	0.06	*0.03*	11.79	*2.73*
		High	3.71	*2.82*	17.77	*13.05*	193.00	*17.00*	0.05	*0.02*	12.13	*1.83*
		Int.	5.90	*2.94*	28.68	*14.11*	201.00	*19.00*	0.06	*0.03*	11.87	*2.03*
	Postinterruption text	D.Int	16.82	*3.28*	76.66	*12.74*	216.00	*15.00*	0.16	*0.06*	10.01	*1.68*
		High	16.97	*3.15*	76.41	*12.19*	218.00	*16.00*	0.15	*0.07*	9.71	*1.50*
		Int.	17.19	*3.28*	77.52	*12.35*	218.00	*16.00*	0.16	*0.06*	9.91	*1.61*

Note: Int. Type = interruption type; D.Int = delayed interruption; High. = highlighted; Int = interruption. Reading time = the summed duration of fixations in seconds. Number of fixations = the summed number of fixations across text. Mean fixation duration = the mean duration of the first-pass first fixations. Regression probability = the probability of regression from words within the portion of text. For mean length of saccades, 1 char. (character) = 0.94 degrees of visual angle.

Results and discussion

A summary of the data is presented in Table 2. The first set of analyses concerned the initial reading of the preinterruption text, before the reader had reached the target word. Analyses revealed no significant effects of interruption type for all dependent measures (all ps > .05). On average, participants took 16.23 s to read the preinterruption text and made 62.16 fixations, with a mean fixation duration of 220 ms, a regression probability of around 16%, and a saccade length of 9.05 characters (aggregated across all interruption types). Within this preinterruption section, there was once again no evidence of participants slowing down in expectation for an upcoming interruption, with measures of fixation duration and the probability of regression virtually identical across lines 4 and 5 and lines 6 and 7 (fixation duration: lines 4 and 5, $M = 224$ ms, $SE = 4$; lines 6 and 7, $M = 224$ ms, $SE = 3$; regression probability: lines 4 and 5, $M = .16$, $SE = 01$; lines 6 and 7, $M = .16$, $SE = .01$; $p > .1$ for all main effects and interactions).

The second main set of analyses concerned the rereading of the preinterruption text following the interruption. Analyses revealed a significant effect of interruption type for reading time, $F(2, 54) = 13.57$, $p < .001$, $\eta_p^2 = .33$. In line with our expectations, post hoc analysis indicated that the readers spent much less time rereading the preinterruption text in the highlighted condition than in the interruption condition (3.71 s vs. 5.90 s; $p < .001$). In addition to the well-documented process of reinstating the previously read information in memory, this result provided strong evidence for the hypothesis that searching for the point in the text where the interruption occurred was one of the important cognitive processes taking place upon reading resumption. However, in contrast to our expectations, there was once again no significant difference between the interruption and delayed interruption conditions in terms of reading time (5.90 s vs. 5.26 s; $p = .17$). This indicates that readers did not use the 8-s interruption lag to prepare themselves for later reading resumption. In respect to the other eye movement measures, there were significant effects of interruption type for the number of fixations, $F(2, 54) = 15.48$, $p < .001$, $\eta_p^2 = .36$, mean fixation duration, $F(2, 54) = 5.36$, $p < .01$, $\eta_p^2 = .17$, and regression probability, $F(2, 54) = 5.23$, $p < .01$, $\eta_p^2 = .16$. Post hoc analysis indicated that readers made fewer fixations (17.77 vs. 28.68), had shorter fixations (193 ms vs. 201 ms), and had lower regression probability rates (4.8% vs. 6.4%) in the highlighted condition than in the interruption condition (all ps $< .05$). In contrast, there were no significant differences between the interruption and delayed interruption conditions across these eye movement measures (all ps $> .1$).

The third set of analyses concerned the postinterruption text during the postinterruption period. Analyses revealed no significant effect of interruption type across all eye movement measures (all ps $> .05$).

The analyses conducted on comprehension scores and difficulty ratings revealed no significant effects (all ps $< .1$). As in Experiment 1, the comprehension scores were very high: $M = .90$ and $SD = .11$ for the interruption trials, $M = .89$ and $SD = .12$ for the highlighted trials, and $M = .89$ and $SD = .11$ for the delayed interruption trials. The difficulty ratings means and standard deviations were as follows: $M = 3.14$ and $SD = 0.81$ for the interruption condition; $M = 3.07$ and $SD = 0.90$ for the highlighted condition; $M = 3.17$ and $SD = 0.79$ for the delayed interruption condition.

In sum, the results provide strong evidence for our claim that, in addition to the well-studied cognitive process of reinstating previously read information in memory, the process of searching for the point in the text where the interruption occurred is another important cognitive process involved in recovering from interruptions in reading. The reason why this second process plays such a central role may be because spatial memory is very weak and short-lived in reading (M. H. Fischer, 1999; Inhoff & Weger, 2005; Rothkopf, 1971; Therriault & Raney, 2002; Weger & Inhoff, 2007). In contrast, the results were not consistent with the predictions we derived from the memory for goals model (Altmann & Trafton, 2002, 2007) and previous interruption lag studies (e.g., Hodgetts & Jones, 2006a). As in Experiment 1, the resumption lags were no different in the presence of an interruption lag.

GENERAL DISCUSSION

The aim of the present study was to gain new insight into the influence of interruptions in reading by using an eye movement paradigm. The research focused on two specific issues. First, we examined whether reading resumption can be aided by the presence of an interruption lag prior to the interruption being initiated. Second, we investigated whether spatial memory plays a central role in recovering from interruptions during reading. We obtained three primary results: (a) providing a visual cue (i.e., a highlighted word) upon resumption to indicate the point in the text where the interruption occurred substantially aided task resumption, (b) the time spent rereading previously read text upon resumption was remarkably short, especially considering that the interruptions were long (60 s) and that the processing of novel text following the interruption was not impaired but rather slightly facilitated, and (c) neither a 3-s nor an 8-s interruption lag without the primary text seemed to aid reading resumption.

One important issue addressed by the present study was the role played by spatial memory in reading resumption. Providing a visual cue (i.e., a highlighted word) upon resumption, indicating the point in the text where the interruption occurred, substantially facilitated task resumption. This finding could be considered rather trivial; a visual cue marking the interruption point should be expected to aid the resumption of reading. However, even with the availability of a visual cue it is possible that extensively rereading the text prior to the interruption point is necessary to reinstate text representations and facilitate reading of text past the interruption point. Here we have identified that this is not the case; continuing reading for comprehension from the interruption point is not hampered if the previously read text is almost completely skimmed. This finding provides some support for the claim that searching for the point in the text where the interruption occurred is a central cognitive process involved in reading resumption, as spatial memory is very weak and short-lived in reading (see M. H. Fischer, 1999). This finding is not at odds with the memory for goals model or the LTWM theory but neither of the two models explicitly take this spatial (or visual search) component into account (see Ratwani & Trafton, 2008). Instead, both models focus exclusively on nonspatial memory processes; including a spatial component within these models may improve their predictive ability in relation to reading.

The second important finding was that the time spent rereading previously read text upon resumption was remarkably short. This finding complements the assumption that substantial rereading of previously read text is not necessary to aid the continuation of reading on novel text (cf. Ericsson & Kintsch, 1995). Although the interruptions were longer than any interruptions previously manipulated in reading studies (60 s in the present study compared to 30 s common to previous studies), readers demonstrated remarkably short resumption lags compared to the initial time spent reading the text. Furthermore, the processing of novel text seemed even slightly facilitated compared to baseline (i.e., shorter reading time on postinterruption text following an interruption in Experiment 1; see Cauchard, Cane, & Weger, 2011, for a replication and a detailed interpretation of this effect). Altogether, these results are consistent with core assumptions of the LTWM theory: that information can be rapidly safeguarded into long-term memory whilst reading, so that long-term memory serves as an extended working memory. When readers resume reading a text after an interruption, even a long and demanding one, words serve as effective cues to reinstate the text representation that has been safeguarded in long-term memory (see also Oulasvirta & Saariluoma, 2006). It must be noted that the short resumption lags seem also at odds with the memory for goals model. The model predicts the activation level of the primary-task representations to decay almost completely beyond a demanding 30-s interruption. Therefore, after a demanding 60-s interruption, the representation should have decayed to a point where it is very difficult to retrieve. The very short resumption lags we observed show that this was not the case.

Another important assumption of the memory for goals model (Altmann & Trafton, 2002, 2007) is that individuals can prepare themselves during an interruption lag to more easily resume the primary task after the interruption. We tested this prediction in the context of a reading task using an interruption lag with the primary text removed. In this context, neither a 3-s interruption lag (Experiment 1) nor a 8-s interruption lag (Experiment 2) seemed to aid reading resumption. These results are at odds with previous studies that have reported interruption lag effects (Altmann & Trafton, 2004, 2007; Hodgetts & Jones, 2006a; Trafton et al., 2003). One possible explanation for the discrepancy between our results and previous findings is that the interruption lags were not beneficial in our experiments because no primary task information was available during the interruption lag. This is in contrast to methods adopted across previous studies. However, it must be noted that interruption lag effects have also been found in the absence of primary task information in tasks unrelated to reading (see Altmann & Trafton, 2007). An alternative explanation is that interruption lag effects (and potentially other interruption effects) depend on the particular task at hand. What differentiates resumption processes in an interrupted reading task and in a goal-oriented (e.g., problem solving) interrupted tasks is that the content of the representations stored in memory are different: text structure versus goals and means-ends structures, respectively. Interruption lags may, therefore, be less beneficial in reading tasks than in other tasks (e.g., problem solving) due to inherent task demand properties —that is, the time given for consolidation may be more easily utilized in tasks that involve means-ends goal representations than those that involve text representations.

Future research needs to build on the present work by examining whether including text during the interruption lag aids the return back to reading. This would help clarify whether it is specifically reading that does not appear to benefit from time-outs prior to responding to interruptions, or whether it is the availability of the text during the interruption lag that influences the effectiveness of the interruption lag. Similarly, future research might examine in more detail whether introducing the interruption at different points during a sentence may produce different effects. For instance, it might aim to identify whether having interruption halfway through the sentence hinders subsequent resumption following an interruption.

Some important practical implications can be derived from the present study. Based on our findings, there is a way to aid the continuation of reading after an interruption that can be easily applied in everyday work settings: to put a mark in the text indicating where the interruption occurred. When reading on a computer screen, readers may be advised, for instance, to use their mouse-cursor to create such a mark. Upon returning to the text after the interruption, the mark can minimize the undesirable visual search process while preserving the need for the reader to reinstate previously read information in memory. Importantly, returning back to text without rereading substantially previously read text does not inhibit reading resumption or comprehension. Finally, making use of interruption lags to consolidate existing representations in memory does not seem to be a promising strategy in interrupted reading when primary text is unavailable (i.e., when attention is drawn away from the text). It is worth noting that even for the tasks where interruption lags were found to facilitate task resumption, the cost–benefit ratio of the interruption lags was never beneficial. Trafton et al. (2003) found that an 8-s interruption lag saved 3 s at resumption, while Hodgetts and Jones (2006a) found that a 2-s interruption lag saved 2 s at resumption, both indicating that the introduction of a lag thus appears to be an inefficient (and in many conditions probably also impractical) way to deal with interruptions.

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APPENDIX

Example paragraph (interruption trigger word is highlighted), related comprehension question, and possible answers.

> The guitar is a wonderfully versatile instrument. It is portable, needs no accompanist because it provides harmony as well as melody, and has an intrinsically beautiful tone which is sensitive to human touch. The higher levels of solo playing take time to practice, as with any instrument, but the guitar can be a pleasure from the first day and the first successful sounding of a chord. The study of guitar is exciting because there is always something new to discover and achieve, and as long as you live there will always be more. For some it becomes a social activity through local guitar societies, with the chance to play duets or ensembles with other enthusiasts and perhaps perform for the group. For others it becomes like meditation, a quiet hour after a day's work which lifts the mind gradually from the humdrum to the sublime. In this respect the guitar is less an instrument, more of a way of life.

According to the paragraph, what can take time to practice?

(a) solo playing.
(b) performing in a group.[1]

[1] Excerpt taken from F. Noad, *The complete idiot's guide to playing the guitar.* New York, NY: Alpha, 2002, p. xiii.