Skim Reading: An Adaptive Strategy for Reading on the Web

Conference Paper · June 2014

DOI: 10.13140/2.1.2900.5443

CITATIONS
2

READS
206

3 authors, including:

Gemma Fitzsimmons
University of Southampton
14 PUBLICATIONS **72** CITATIONS
SEE PROFILE

Denis Drieghe
University of Southampton
78 PUBLICATIONS **2,657** CITATIONS
SEE PROFILE

Skim Reading: An Adaptive Strategy for Reading on the Web

Gemma Fitzsimmons, Mark J Weal, Denis Drieghe
University of Southampton
England, UK
{G.Fitzsimmons, M.Weal, D.Drieghe}@soton.ac.uk

ABSTRACT

It has been suggested that readers spend a great deal of time skim reading on the Web and that if readers skim read they reduce their comprehension of what they have read. There have been a number of studies exploring skim reading, but relatively little exists on the skim reading of hypertext and Webpages.

In the experiment documented here, we utilised eye tracking methodology to explore how readers skim read hypertext and how hyperlinks affect reading behaviour. The results show that the readers read faster when they were skim reading and comprehension was reduced. However, the presence of hyperlinks seemed to assist the readers in picking out important information when skim reading. We suggest that readers engage in an adaptive information foraging strategy where they attempt to minimise comprehension loss while maintaining a high reading speed. Readers use hyperlinks as markers to suggest important information and use them to read through the text in an efficient and effective way. This suggests that skim reading may not be as damaging to comprehension when reading hypertext, but it does mean that the words we choose to hyperlink become very important to comprehension for those skim reading text on the Web.

Categories and Subject Descriptors

H.1.2 [**User/Machine Systems**]: Human Information Processing

Keywords

Hyperlinks; Reading; Skim reading; Web Science; Psychology; Human Computer Interaction; Eye movements

1. INTRODUCTION

We do not always choose to read carefully, sometimes we can skim read for a general impression of the information presented. When there is a large amount of information to read, it is not always efficient or necessary to read everything in great detail. This may equally be true of reading on the Web. There is so much information and text to read that to carefully read and retain everything would not be always possible. Therefore, a strategy of skim reading may be the most effective way to move through the information quickly. However, there is the concern that during skim reading some comprehension may be lost [4, 6, 9, 12]. In this paper, we report an experiment that examined reading behaviour by recording the eye movements of participants when they read text presented to them. The participants were instructed to read for comprehension or to skim read and they were asked a number of comprehension questions about the texts being read. We will begin by describing the previous research regarding skim reading and reading on the Web, and discuss how the experiment documented here augments what is known regarding how people read and skim read hypertext.

WebSci '14, June 23 - 26 2014, Bloomington, IN, USA

ACM 978-1-4503-2622-3/14/06…$15.00.
http://dx.doi.org/10.1145/2615569.2615682

1.1 Eye Movement Methodology

Eye movements during reading are made up of fixations and saccades. When the eye is moving, this movement is called a saccade. In between these saccades our eyes are relatively still, this is called a fixation. We take in visual information during fixations and vision is mostly suppressed during saccades to avoid seeing a blur or smear [13].

Saccades are necessary due to the anatomy of the eye and the retina. The retina contains many photoreceptors called rods and cones. Cones are necessary for high visual acuity. The majority of the cones in the retina are in an area called the fovea which covers about 1° degree of visual angle on either side from the fixation point. Moving beyond the fovea, there is a large reduction in the number of cones and therefore a high acuity drop-off. In order to read, we need the words to be positioned on the high acuity fovea to be able to process them. As a result, we need to move our eyes so that the fovea can be utilised to gain the most visual information while reading. It is this fact that makes the eye tracking methodology so useful. Dependent on the size of the object on the retina, individuals need to move their eyes and actually fixate objects in order to see them in detail and process them.

Recording eye movements is an objective way of collecting data about behaviour and a number of studies have shown that eye movements provide an unobtrusive, real-time behavioural index of visual and cognitive processing [10, 19, 20]. The recording of eye movement behaviour enables the researcher to explore the cognitive processes of the online reader in detail.

The experiment we report in the present paper uses eye tracking methodology and building on the existing base of eye movements and reading research (for reviews see [19, 20]) to explore how individuals read hypertext. First, we will discuss the present debate on how hyperlinks may affect reading behaviour.

1.2 Reading Hypertext

There has been a considerable debate as to whether in-text hyperlinks hinder reading. Carr [3] suggested that hyperlinks serve as a distraction and subsequently hinder comprehension of the text. This, he has argued, is because having to evaluate hyperlinks and navigate a path through them is cognitively

demanding and draws attention away from the primary task of processing and comprehending the text itself.

Other researchers have suggested that hyperlinks may cause a disruption to reading due to the fact that the salient (typically blue) hyperlinked words attract the attention of the users away from processing and comprehending the text. Related to this, Simola, Kuisma, Oorni, Uusitalo and Hyönä [22] demonstrated that the presence of salient advertisements within a Web page (e.g. those containing motion) can attract disrupt reading of the text and draw the attention of the user. Elsewhere, it has been shown in contrast that learning from electronic texts can be aided by the presence of hyperlinked words, with participants more likely to retain information from hyperlinked words [16].

We previously conducted an experiment [7] exploring how people read text that contained a blue hyperlinked word within a Wikipedia environment. We found that having hyperlinked words in the text did not affect the processing of the text, but when the hyperlinked word was a more difficult or *low frequency* word (such as *skin* vs the low-frequency *pelt* or *plant* vs *shrub*), participants were more likely to re-read the preceding text. These extra fixations did not affect overall reading times suggesting that having salient blue hyperlinks in the passages of text did not hinder overall reading behaviour.

Taken together, these previous studies provide conflicting views in terms of whether hyperlinks are beneficial or are a hindrance to reading. Despite the fact that there has been relatively little research examining how hyperlinks influence reading behaviour on the Web, this is nonetheless an important issue to examine considering how much of our time spent on the Web involves reading and comprehending text. Specifically, if hyperlinks are automatically generated, for example by cross-referencing documents in Wikipedia [14], with no human-authored intentionality, it is important to understand how we read hyperlinked text in order to make sure that the efficiency of reading is not unnecessarily disrupted.

The following section discusses the research on skim reading and whether it is an effective reading strategy when there is a large amount of text to read, or whether there is a comprehension trade-off that makes skim reading faster, but not necessarily more effective when trying to gain comprehension of the text being read.

1.3 Skim Reading

In typical reading studies (for reviews, see [19, 20]), researchers want to ensure that participants are reading for comprehension and fully processing the sentences that are presented. Comprehension questions are often inserted between trials so that researchers can be certain that the participants were fully processing the sentences. However, when reading outside of the laboratory, people may 'skim' through the text and not fully process all aspects of the text that has been presented to them. Current literature suggests that reading on the Web may involve skim reading [11, 15]. Liu [11] suggests that there is a screen-based reading behaviour that is characterised by 'more time spent browsing and scanning, keyword spotting, one-time reading, non-linear reading, and reading more selectively, while less time is spent on in-depth reading, and concentrated reading.' I will now discuss the present literature on skim reading.

One of the first experiments exploring skim reading behaviour used eye movement methodology to investigate the differences in how people read when they are reading normally or reading quickly. Just and Carpenter [9] studied three different types of reading: normal reading; skim reading; and speed reading (using participants who had graduated from a speed reading course). Just and Carpenter [9] suggested that readers increase their speed by sacrificing the amount they understand from the text, thereby exhibiting a trade-off of greater speed at the cost of reduced comprehension. They found that speed readers were three times faster than normal readers and the skimmers were two and a half times faster than the normal readers in reading through the text presented to them. The eye movement analyses showed that the skimmers and speed readers fixated fewer words than the normal readers and the normal readers had longer fixations when they fixated a word. Speed readers and skimmers were also more likely to skip over multiple words compared to the normal readers.

In terms of which words were fixated, Just and Carpenter [9] found that the normal readers fixated twice as many content words when compared to function words during normal reading. Reasoning that this may have been due to differences in word length between content and function words, they explored their data, but found that readers were more likely to fixate three letter content words than three letter function words, which is consistent with the standard pattern seen in word skipping research [2]. However, a slightly different result was observed for the speed readers and skimmers. They were also more likely to fixate long words compared with short words, but they did not discriminate between short content words and short function words, both were skipped as often as each other suggesting that word length is an important factor for speed readers and skimmers when planning where to move the eyes. Also, because the speed readers and skimmers often skipped more words, the readers are fixating words far into their peripheral vision and therefore cannot gain any useful information other than discriminating word boundaries due to the reduced acuity in the periphery.

Just and Carpenter [9] also examined gaze durations. The gaze durations were shorter for the speed readers and skimmers, who spent on average 100 ms (around one–third) less time on each fixation. However, even with this reduction in fixation times the speed readers and skimmers still showed similar effects of frequency (low frequency words had longer fixation times compared to high frequency words) and word length (longer words had longer fixation times compared to shorter words) as those seen in normal readers, but the sizes of the effects were much smaller. All three groups showed changes in their reading speeds dependent on the sub-section of text they were reading. These changes in speed were roughly parallel across the groups suggesting that they slowed down and speed up their reading rate on the same sub-sections of text. The speed readers and skimmers tended to make more fixations rather than make longer fixations when they spent longer on a section of text. Just and Carpenter [9] suggested that the reading rate varied depending on the section of the text because of "local variables that are idiosyncratic to the text", meaning that some sections of text have denser levels of information, or more difficult information compared to other sections of the same text. They dismissed the suggestion that readers may slow down for sections of text rated independently as more important as they have no suggestion that this could be true from their findings. Instead they suggest that if the reader encountered a difficult to parse phrase they may need to sample more densely in order to understand the text.

Finally, Just and Carpenter [9] found that in terms of comprehension the normal readers had better comprehension than

the others two groups. When comparing the speed readers to the skimmers, the speed readers answered more questions correctly (but, it was mostly restricted to general questions rather than those concerning specific details), in spite of reading on average 100 words per minute faster than the skimmers. This is interesting because it would seem that the speed reading training has assisted their speed readers and reduced the speed-accuracy trade off compared to the skimmers.

Other researchers have also shown a reduction in comprehension when reading rate increased. Carver [4] displayed passages of text to participants and gave them varying amounts of time to read the passages. When testing the participants with comprehension questions, those who had the shortest time to read the text performed the worst. This suggests that by increasing reading speed, comprehension is reduced. However, it is difficult to see if comprehension is reduced globally across the text. Other researchers have rated each sentence in the text by independent participants and explored if skim reading is used to skim over the unimportant pieces of text rather than just skim read all of the text. For example, Masson [12] manipulated the time participants had to read passages of text and tested their recognition memory for the text in the passages. The recognition rates decreased when the participants' time to read the text decreased. Also, the faster the text was read, the longer the reaction times were to respond to the recognition questions. However, this was only true for those sentences that were rated as 'unimportant' (as judged by a different set of independent participants). The sentences judged as 'important' did not show the comparitively longer reaction times. Masson [12] suggested that this was due to participants focusing more on relevant and important imformation in the passages to enable faster processing of the text, and paying less attention to the 'unimportant' sentences in order to read more efficiently.

Alternatively, Dyson and Haselgrove [6] found that when participants were asked to either read normally or at a self-paced faster speed (approximately twice as fast) those who read faster had lower scores on the comprehension task. The comprehension task consisted of multiple choice questions and those who read faster recalled more general information and less specific details, but there was no interaction between reading speed and the type of information the participants remembered.

More recently, Reader and Payne [21] examined whether skim readers focus on extracting information from the more important sentences contained within text. Participants were given four texts of different difficulties. Participants spent more time on the higher-level/more difficult texts. Reader and Payne [21] suggested that this was evidence of an 'adaptive allocation of attention' in skim reading tasks, a so-called satisficing strategy.

The concept of a satisficing strategy comes from information foraging research where it is assumed that the readers are sensitive to their 'information gain' (how much useful information they are getting over time) and use this as a basis for what to read and when to stop reading and move on. For example, a reader is monitoring their information gain and they have a threshold of how much information they are happy to get in a certain amount of time. If that information gain drops below that threshold the reader will then stop reading that particular piece of text and move on to a new patch where they might gain more information in the same amount of time.

Pirolli and Card [17] used a metaphor of a bird foraging for berries in patches of bushes as an example of information foraging. The bird must decide how long to spend on one patch before expending time moving onto a new patch to forage for berries. The problem is at what point does the bird decide to move from the one patch to a new one? The most efficient time to leave for a new patch is when the expected future gains from foraging in the current patch decrease to such a level that it is better to expend time moving to a new patch where the future gains may be greater.

Reader and Payne [21] suggested that this information foraging approach of satisficing can be applied to skim reading if we assume that the 'patches' are patches of text or paragraphs, and the reader has a threshold for their information gain that is influenced by the amount of time they have to read the text. If the reader has a short amount of time to read the text, they will want to have a lower threshold for information gain. If they are not receiving enough information from a patch they will want to realize this quickly and move on to a patch that has a higher information gain to make the most efficient use of the limited time. If this is true then the readers will focus on the most important information patches and leave the patches with less important information if their time is limited.

Duggan and Payne [5] conducted several experiments to test if participants focused on the more important information in the text when skim reading. They found that readers who were engaged in skim reading had better memory performance for important details from the text, but not for the unimportant details. Where previous studies that have explored skim reading have shown a decline in comprehension performance, Duggan and Payne [5] found an improvement in comprehension and found higher scores in comprehension questions for sentences rated independently as 'important'. This suggests that skim reading is an adaptive satisficing strategy. By leaving text before it is processed in depth and when information gain begins to drop, readers can efficiently move through the text at an increased speed, while trying to keep comprehension high. Skim reading is a trade-off whereby the reader is trading depth of comprehension for speed, but while trying to minimize the loss of comprehension by using an effective strategy to move through the text quickly without losing comprehension.

The present paper focuses on how hyperlinks impact on skim reading behaviour and how individuals sample the text and extract information from it. With the large amount of information online it can be safely assumed that skim reading is a common behaviour, an efficient way of gaining as much information as possible in the shortest amount of time, while trying not to sacrifice comprehension too much. Hyperlinks may be used to assist in the strategy of determining what parts of the text contain important information and what should be read to gain comprehension.

An experiment was conducted to explore this issue. Participants were either instructed to read normally for comprehension or asked to skim read passages of text that resemble a Wikipedia page. Target words within the passages were manipulated to either be black or blue (resembling a hyperlink) and also their difficulty was manipulated by making the target word either a highly frequent common word (such as *plant*), or a low frequency uncommon word (such as *shrub*). Between each page of text the participant was asked comprehension questions which were either related to important or unimportant sentences in the text (as rated by independent participants not taking part in the main experiment). From previous research we predicted that readers would read faster when asked to skim read, but would have reduced comprehension. It was difficult to suggest whether there

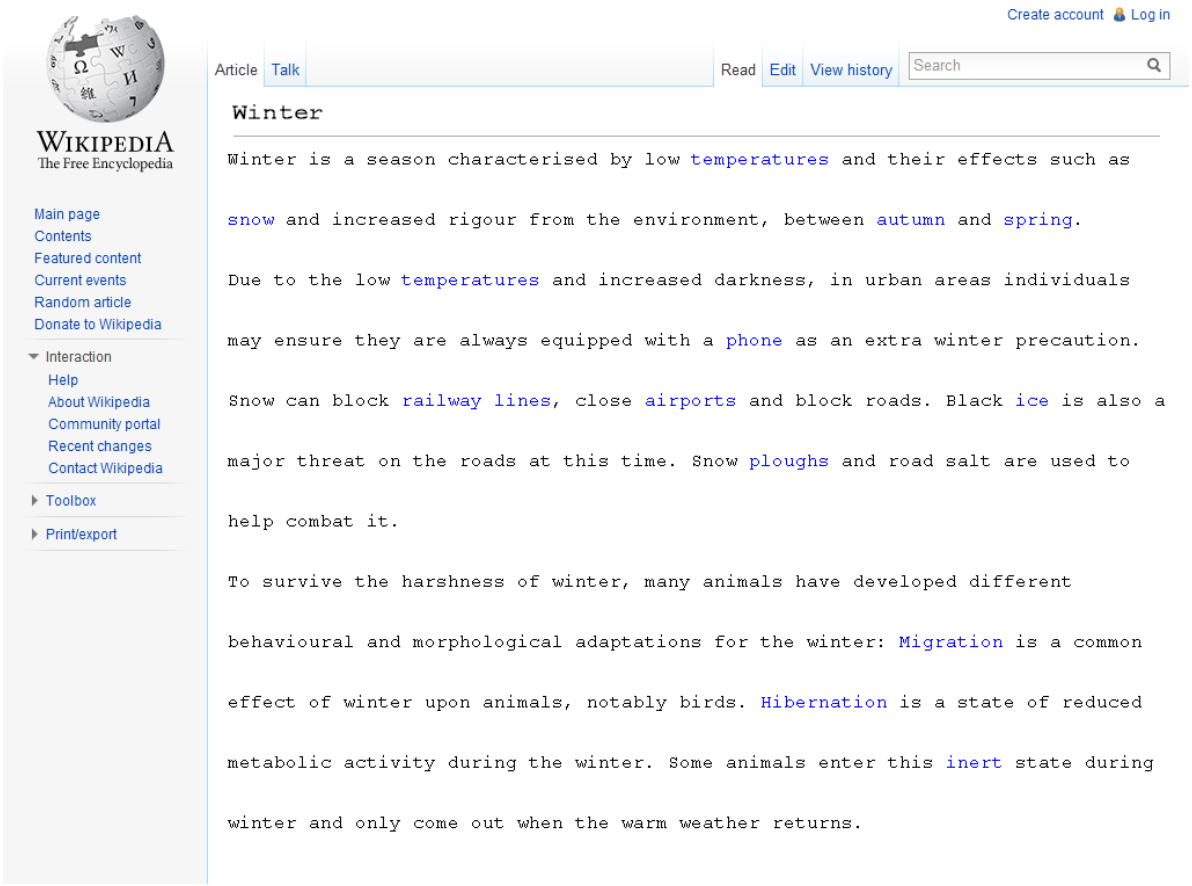

Figure 1. Example stimuli, an edited Wikipedia article.

would be a difference in the comprehension of important and unimportant information because previous research has had conflicting results. However, if skim reading is an efficient strategy to read through text the fastest way possible while minimising comprehension loss then we would expect that the skim readers will perform more poorly on comprehension question about the unimportant information.

2. EXPERIMENT

2.1 Method

Thirty-two native English speakers with normal or corrected-to-normal vision took part in the experiment. Eye movements were measured with an SR-Research Eyelink 1000 system running at 1000Hz (i.e. one sample every millisecond). Viewing was binocular, but eye movements were only recorded from the right eye. The stimuli consisted of forty edited Wikipedia articles (see Figure 1) on a variety of neutral topics. One-hundred and sixty target words were embedded in sentences (one target word per sentence) and four sentences were inserted into each Wikipedia article. In total there were 8 conditions in a 2 (Task Type: Normal, Skimming) x 2 (Word Type: Linked, Unlinked) x 2 (Word Frequency: High, Low) within participants design. The text on the screen was instructed either to be read normally or to be skim read. This was blocked so that the first twenty stimuli were to be read normally and the second twenty to be skim read. We did not counterbalance the Task Type out of worry that the normal reading blocks would be influenced by first having to skim read. Participants were not told they were going to be skim reading until just before that half of the experiment was due to begin, so as not to effect the first part of the experiment which was to be read normally. At a target word level, the target words within these articles were either displayed in blue or black to denote if the word was a hyperlink or not. There was also a word frequency manipulation where the target word is either high or low frequency. The word frequencies were taken from the Hyperspace Analogue to Language (HAL) corpus, which consists of approximately 131 million words gathered across 3,000 Usenet newsgroups. The frequency norms were used to extract both high and low frequency words to create the experimental stimuli. The high frequency words had an average log transformed HAL frequency of 9.94 and the low frequency words have an average log transformed HAL frequency of 5.81 (according to the norms collected in the HAL corpus [1]. All target words were 4-7 characters in length, the average was 5.60 characters. Word length was matched for each high/low frequency pair).

All characters were lowercase (except when capitals were appropriate) and presented in a monospaced Courier font. The display was 73 cm from the participant's eye and at this distance three characters equal about 1° of visual angle. The participants' head was stabilised in a head/chin rest to reduce head movements that could affect the quality of the calibration of the eye tracker. At the beginning of each trial the participant had to look at a fixation point on the screen. When the eye tracker registered a stable fixation on the fixation point, the sentence was displayed

Table 1. Fixed effect estimates for all eye movement measures in Experiment.

	Skipping Probability Percentage	Single Fixation Duration	Go-Past Times
Intercept	0.09	5.32 ***	5.67 ***
Word Frequency	-0.19 **	0.09 **	0.09 *
Word Type	0.14	0.01	-0.06
Task Type	0.01	-0.04	-0.13 ***
Word Type x Task Type	0.57 ***	0.01	0.01
Word Frequency x Word Type		0.05	0.06
Word Frequency x Task Type		-0.01	-0.08
Word Frequency x Word Type x Task Type		-0.13 *	-0.10

* $p<.05$, ** $p<.01$, *** $p<.001$

Table 2. Means of eye movement measures (in ms). Standard deviation in parentheses.

Task Type	Word Type / Word Frequency	Skipping Probability Percentage	Single Fixation Duration (ms)	Go-Past Times (ms)
Normal	**Linked/High**	52 (20)	221 (44)	378 (223)
	Linked/Low	48 (22)	233 (37)	370 (164)
	Unlinked/High	54 (19)	212 (37)	233 (116)
	Unlinked/Low	51 (20)	246 (45)	375 (140)
Skimming	**Linked/High**	52 (23)	201 (27)	295 (128)
	Linked/Low	48 (22)	221 (35)	284 (76)
	Unlinked/High	68 (18)	204 (41)	263 (94)
	Unlinked/Low	63 (18)	205 (31)	250 (50)

ensuring that the first fixation fell at the beginning of the text. This is to be certain that the reader is starting at the beginning of the passage and not starting the trial by picking up information from later in the text. When participants finished reading they confirmed they had finished by pressing a button on the response box in front of them. They were then presented with four comprehension questions in a random order. Two questions were related to sentences that were rated as most important by independent participants and two were related to sentences rated as least important. Participants responded to the questions by pressing the appropriate button on a response box. After the questions the next trial would appear. The experiment lasted approximately 90 minutes.

2.2 Results

Eye trackers record a large amount of data (one sample every millisecond) and this data can contain erroneous fixations that are not representative of the dataset. In some cases, these erroneous or outlier fixations will be caused by errors in the eye-tracker (detected by the algorithms used to track the eyes); in other cases, the participant may have had a lapse of concentration, leading to very long fixation durations. Regardless of the cause, and because we were interested only in those instances when the participants were paying attention and reading the text, we cleaned the dataset before conducting our statistical analyses. In the current experiments we followed the standard procedures for cleaning our data that have been adopted by the reading research community. Trials where there was tracking loss were removed prior to analysis. Fixations shorter than 80 ms that were within one character of the previous or following fixation were merged and all other fixations shorter than 80 ms or longer than 800 ms were removed to eliminate outliers (5.43% of total dataset). When calculating the eye movement measures data that were more than 2.5 standard deviations from the mean for a participant within a specific condition were removed (<1% of dataset). Data loss affected all conditions similarly.

Around each target word an *interest area* was drawn. The interest area is the size of the target word including the space preceding it. The analyses below are conducted using the fixations that landed on the target word, within the interest area drawn around it.

2.2.1 How does Skim Reading affect the Way we Read Hypertext?

Participants were significantly faster to read the passages when they were skim reading ($t(31)=17.38$, $p<.001$). The average time spent reading normally was 39 seconds (SD=8), compared to only 20 seconds ($SD=6$) when asked to skim read. This supports

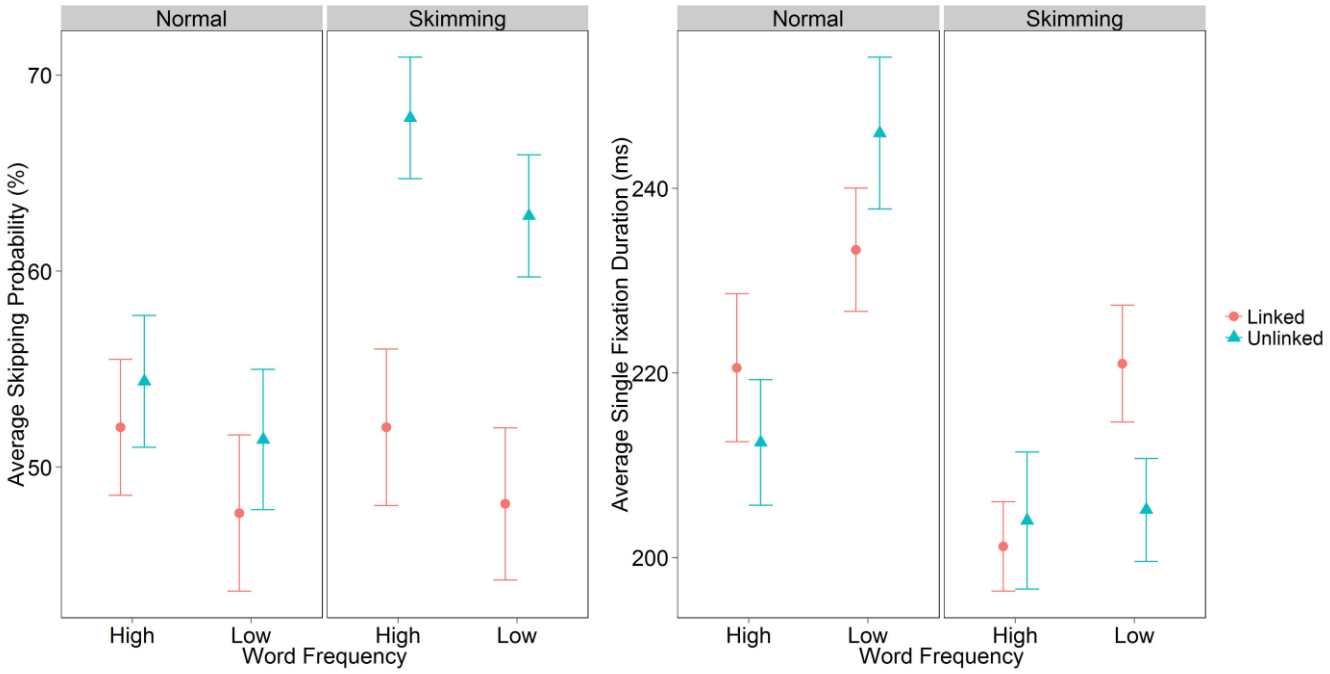

Figure 2. Task Type x Word Type interaction in skipping probability and Task Type x Word Type x Word Frequency interaction in single fixation durations.

previous suggestions that skim reading is around twice as fast as normal reading [6, 9, 12].

We focused out analysis on three key eye movement measures: *Skipping probability*, *single fixation duration* and *go-past times*. *Skipping probability* is the probability that the target word is skipped in first-pass reading. Skipping rates are used to show the ease of processing a word. If a word is easy to process than is may be fully processed prior to fixating it and skipped completely in first-pass reading. *Single fixation durations* are when the reader makes only one single fixation on the target word in first-pass reading. It is used as a measure to describe how easy a word is to process [19]. Because this measure only includes times where the target word was only fixated once it is one of the cleanest measures to use to represent how difficult a word is to process and can give us a good estimate of how difficult a word is to process. Also, when the target word was fixated, in 93.91% of the cases it received a single fixation. Therefore, we limited the fixation duration analyses to when there was a single fixation on the target word. *Go-past times* are the accumulated time from when a reader fixates the target word until the reader passes to the right after the target word. This measure is often used to explore if a reader has had trouble integrating the target word because it includes the regressive (backward-directed) fixations when a reader has to re-read preceding content.

A series of linear mixed-effects models (lme) using R [18] were used to examine the eye movement measures. Due to the large variation of behaviour often observed between participants and items the models specified participants and items as crossed random effects. The significance values and standard errors reported reflect both participant and item variability. These analyses have the advantage that they result in considerably less loss of statistical power in unbalanced designs due to missing values than traditional ANOVA's. This is especially important for fixation times when the target word is skipped often, which is the case in this experiment. The *p*-values were estimated using posterior distributions for model parameters obtained by Markov-Chain Monte Carlo (MCMC) sampling.

The three independent variables were included as fixed factors: Task Type (Normal, Skimming), Word Type (Linked, Unlinked) and Word Frequency (High, Low). Model comparisons showed that the three-way interaction between the three fixed factors and the two-way interactions with Word Frequency had to be removed from the skipping probability model because it did not contribute significantly to the fit of the data. All fixed effects estimates are shown in Table 1. The means for all the measures are shown in Table 2.

There was a significant effect of Word Frequency across all eye movement measures. The high frequency words were skipped more often than the low frequency words and if the target was fixated, the fixations times were significantly shorter when the target word was high frequent. This replicates previous experiments that have demonstrated that low frequency words are skipped less often and have longer fixations times because they are more difficult to process than high frequency words [8].

There was no main effect of Word Type on the local analyses, whether the target word was linked had no effect on fixation times (all *p*'s larger than 0.1). This suggests that target words are not more difficult to process when they are linked, replicating our previous findings [7]. However, there was a marginal effect observed in skipping probability. When the target word was linked it was less likely to be skipped. This was qualified by a two-way interaction in skipping probability between Word Type and Task Type (see Figure 2). Subsequent contrasts showed that there was no difference in skipping probability when the target word is linked or unlinked (z=1.69, SE=0.08, p=0.09), but there

was a significant difference in the skim reading condition. Linked words are significantly less likely to be skipped compared to unlinked words in the skimming condition (z=8.26, SE=0.08, p<001). This suggests that when the readers are skim reading they are attempting to fixate the linked words. They may be using them as anchor points throughout the passage as the reader may think the linked words may be important words within the passage.

As mentioned previously, there was a significant main effect of Word Frequency in single fixation durations. When the target word was fixated there was significantly shorter fixations time when the target was high frequent. This is qualified by a three-way interaction between Task Type, Word Type and Word Frequency (see Figure 2). Contrasts were conducted to explore this interaction. Fixation times were significantly shorter when the passages were skim read compared to when they were read normally (t=-4.43, SE=0.03, p<.001). This supports previous research that shows shorter fixation times when readers are skim reading [9].

When reading normally there is a significant frequency effect seen in both linked (t=2.86, SE=0.01, p<0.01) and unlinked conditions (t=4.20, SE=0.02, p<0.001). Participants fixated low frequency words for longer than the high frequency words. However, when skim reading a frequency effect is present only when the target word is linked (t=3.01, SE=0.01, p<0.01) and there is no frequency effect when the target word is unlinked (t=-0.36, SE=0.02, p=0.75). This is a very interesting result. Because there is an absence of a frequency effect for the unlinked word in the skim reading condition, this suggests that the readers are not lexically processing the unlinked target words they are landing on. The presence of a frequency effect in the linked words in the skim reading condition suggests they are focusing on the linked words and lexically processing them. If, as previous researchers have suggested, readers skim read when reading on the Web, the words we choose to link become very important if readers are processing them at a deeper level, especially if links are used as anchors to the important information within the text.

In normal reading there was no effect of Word Type. The target word being linked or unlinked had no influence on fixation times when the target word was high or low frequent (high frequency: t=0.12, SE=0.01, p=0.89; low frequency: t=1.39, SE=0.02, p=0.16). There was also no effect of Word Type in the skim reading condition when the target word was high frequent (t=1.00, SE= 0.01, p=0.32). However, there were significantly longer fixations on the linked target words in the skim reading condition when the target word was low frequent (t=-2.53, SE=0.01, p<0.01). This is due to the frequency effect being present in the skimming condition for the linked words, but not present for the unlinked words. We see longer fixation times for the low frequent linked words because they are more difficult to process. We do not observe it for the unlinked, low frequency words in the skimming condition because the readers simply were not processing them to the same level, instead focusing on the linked words.

Although the majority of fixations on the target word were single fixations, when the target word was fixated 14.11% of target words had regressions to previous interest areas. Therefore we will also explore go-past times. Go-past times take into account the accumulated time from when the reader first fixated the target word until when they pass to the right, after the target word. All the times where the reader fixated the target word and then made a fixation backward to the preceding text are included in this measure. Again, there was a significant main effect of Word Frequency with longer fixation times for the low frequency words. There was also a main effect of Task Type, go-past times were shorter in the skimming condition compared to normal reading. This suggests that very little re-reading of preceding content occurs during skim reading, the reader is simply trying to read in the most efficient way possible, and thus limiting their re-reading.

2.2.2 Does Skim Reading affect Comprehension?

Each edited Wikipedia article had every sentence within it rated for its general importance to the meaning of the whole passage by twenty independent participants who did not take part in the main eye tracking study. The two most important and two least important sentences had comprehension questions created about them. This rating study served not only as a useful method to create comprehension questions relating to important or unimportant information, but it also allowed us to observe what participants rated as important and if hyperlinks have any effect on this. The importance rating was created using a 5-point Likert scale, where a response of 1 signified "not important" and 5 signified "very important". Participants could respond anywhere on the scale from 1 to 5 how important they found each sentence for the general meaning of each passage. The sentences rated as most important were of course rated significantly higher than those rated as least important (t(79)=11.25, p<.001). The average score for the two most important sentences was 4.42 (SD=0.48) and the average score for the two least important sentences was 2.24 (SD=0.44). What was particularly interesting was the average number of hyperlinks in the most important compared to the least important. The sentences rated as most important had significantly more links than the unimportant sentences (t(79)=30.38, p<.001). The most important sentences had an average of 2.96 (SD=1.94) links per sentences and the least importance sentences had an average of 0.35 (SD=0.73) links per sentence. This suggests that readers may use the presence of hyperlinks as a judge of how important a sentence is, or conversely, important sentences may just contain more hyperlinks.

After each stimulus four comprehension questions were presented to the participants, one at a time. Two of the questions were related to sentences within the passage rated as the most important by independent participants and the other two questions were related to the sentences rated as the least important by independent participants. We examined accuracy using a 2 (Importance: High Importance, Low Importance) x 2 (Task Type: Normal, Skimming) within subjects ANOVA (see Table 3 for means). This revealed a main effect of Task Type (F(1,31)=16.77, p<.0001). The accuracy was significantly lower when the text was being skim read than when it was read normally. This replicates previous research suggesting that comprehension is impaired when skim reading [3, 6, 9, 12]. There was also a marginal main effect of Importance (F(1,31)=3.58, p=0.07). The accuracy improved when the sentence the questions were related to was a sentence externally rated as important. This effect of Importance may be marginal because of the reasonably high accuracy level overall creating a ceiling effect. This suggests that participants were using a strategy to efficiently and effectively read through the text and pick up the most important information, sacrificing the less important information comprehension for increased reading speed. This adaptive satisficing strategy was also suggested by Duggan and Payne [5] when they found similar results in skim reading.

Table 3. Behavioural results containing accuracy, sensitivity and criterion. Standard deviation in parentheses.

Task Type	Importance	Accuracy Percentage	*d'*	*C*
Normal	**High Importance**	91 (5)	3.03 (0.67)	-0.29 (0.35)
	Low Importance	87 (7)	2.63 (0.74)	-0.32 (0.41)
Skimming	**High Importance**	90 (5)	2.9 (0.67)	-0.22 (0.35)
	Low Importance	84 (6)	2.4 (0.64)	-0.4 (0.39)

We used the same methodology for analysing the comprehension question results as Duggan and Payne [5]. They used signal detection theory measures to explore participants' comprehension of the text, focusing on sensitivity (*d'*), which provides an index of overall response accuracy, and response bias (*C*), which provides an index of the extent to which one response is more probable than another. We used these same measures and examined them using a 2 (Importance: High Importance, Low Importance) x 2 (Task Type: Normal, Skimming) within subjects ANOVA (see Table 3 for means). For *d'* there was a main effect of Task Type ($F(1,31)=10.38$, $p<.0001$). The participants' comprehension of the text decreased when they were skim reading. There was also a marginal main effect of Importance($F(1,31)=3.97$, $p=0.06$), which suggests that the participants were to a degree engaged in an adaptive satisficing strategy because they had improved accuracy for comprehension questions relating to the most important information. When examining the bias (*C*) there were no significant differences between the measures (all *F*'s smaller than 2.9, all *p*'s larger than .1). This shows that there was no bias when responding to the comprehension questions.

3. CONCLUSION

The present experiment confirms that participants do read faster when skim reading hypertext and also that, when skim reading, comprehension was impaired compared to normal reading. However, the presence of hyperlinks had an impact on skim reading. Participants were less likely to skip linked words when skim reading and when participants did land on linked words the reader processed them fully, as seen by the significant frequency effect observed in linked target words in the skimming condition. Conversely, participants were less likely to fixate the unlinked words when skim reading. If the participants did fixate the unlinked words they did not seem to be processing them to the same degree as they processed the linked words, this is seen by the lack of a frequency effect on the unlinked words during skim reading.

From the comprehension accuracy we observed that comprehension accuracy declined when the participants were skim reading, but we also found that they performed better on the comprehension questions about the sentences which were rated as more important. This suggests that the participants were prioritising the more important information effectively. We found that the sentences rated as more important contained more hyperlinks on average. Participants may have been using the links as anchors throughout the text if the links denote the most important information. Previously it has been shown that hyperlinks can assist in helping learners retain information [16].

If we take both the findings from the eye tracking and the comprehension results together we can suggest that readers could be engaging in an adaptive satisficing strategy, obtaining a speed-comprehension trade-off which is optimal for the task at hand. Participants may have wanted to read quickly while still retaining as much comprehension as possible. From these findings we suggest that participants used the hyperlinks as markers for the presence of important information and used them in a strategy to skim read through the text in the most efficient way possible.

In terms of Web design and the creation of hypertext documents the key lesson here is that if readers are skim reading on the Web as other researchers have suggested [11, 15] then the words that are chosen as hyperlinks have to be taken seriously. These are the words that the reader will be processing and the reader may be using hyperlinks as a marker for the most important information in the page.

The present experiment represents the first steps in understanding how we read hyperlinked text. Even though in the current experiments participants only engaged in reading behaviour and did not have to make decisions and click any hyperlinks, we obtained significant findings regarding skim reading on the Web which can be built upon in future studies. For the current experiments the aim was to tease apart the process of reading or skim reading hyperlinked text. By taking away the decision making required to navigate through different Web pages, we could therefore focus on how hypertext is read. The results presented here serve as the foundation for future experimentation. By basing our future research on the vast amount of research already conducted on eye movements and reading we can build a fuller understanding of how we read hyperlinked text. Future experimentation will expand our experimental task, which is a simplification of live Web behaviour. We aim to further explore reading on the Web and add the additional complexities such as clicking and decision making now we have the basic findings to build upon.

4. ACKNOWLEDGMENTS

This research was funded by the Research Councils UK Digital Economy Programme, Web Science Doctoral Training Centre, University of Southampton. EP/G036926/1.

5. REFERENCES

[1] Burgess, C., & Livesay, K. The effect of corpus size in predicting reaction time in a basic word recognition task: Moving on from Kucera and Francis. Behavior Research Methods, Instruments, & Computers, 30 (1998), 272-277.

[2] Brysbaert, M., Drieghe, D., & Vitu, F. Word skipping: Implications for theories of eye movement control in reading.

In Underwood, G. ed. *Cognitive processes in eye guidance*. Oxford University Press, Oxford, UK, 2005, 53-78.

[3] Carr, N. G. *The Shallows*. W. W. Norton, New York, NY, 2010.

[4] Carver, R. P. Rauding theory predictions of amount comprehended under different purposes and speed reading conditions. *Reading Research Quarterly*, 19, 2 (1984), 205–218.

[5] Duggan, G. B, & Payne, S. J. Text skimming: The process and effectiveness of foraging through text under time pressure. *Journal of Experimental Psychology: Applied*, 15, 3 (2009) 228-252.

[6] Dyson, M. C., & Haselgrove, M. The effects of reading speed and reading patterns on the understanding of text read from screen. *Journal of Research in Reading.* 23, 2 (2000) 210-223.

[7] Fitzsimmons, G., Weal, M. J., & Drieghe, D. On measuring the impact of hyperlinks on reading. In *5th Annual ACM Web Science Conference*, (Paris, France, 2013),

[8] Inhoff, W. A., & Rayner, K. Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception psychophysics*, 40, 6 (1986) 431–439.

[9] Just, M. A., & Carpenter, P. A. The psychology of reading and language comprehension. Allyn and Bacon, Newton, MA, 1987.

[10] Liversedge, S., & Findlay, J. Saccadic eye movements and cognition. *Trends in cognitive sciences*, 4, 1 (2000), 6–14.

[11] Lui, Z. Reading behavior in the digital environment: Changes in reading behavior over the past ten years. *Journal of Documentation*, 61, 6 (2005) 700-712.

[12] Masson, M. E. J. Cognitive processes in skimming stories. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 8, 5 (1982) 400-417.

[13] Matin, E. Saccadic suppression: A review and an analysis. *Psychological bulletin*, 81, 12 (1974), 899–917.

[14] Milne, D., & Witten, I. Learning to link with Wikipedia. *Proc. CIKM '08*, ACM Press, (2008), 509-518.

[15] Morkes, J., & Nielsen, J. Concise, SCANNABLE, and Objective: How to write for the Web. *Nielsen Norman Group*(1997) http://www.nngroup.com/articles/concise-scannable-and-objective-how-to-write-for-the-web/

[16] Nikolova, O. R. Effects of Visible and Invisible Hyperlinks on Vocabulary Acquisition and Reading Comprehension for High- and Average-Foreign. *Apprentissage des langues et systèmes d'information et de communication*, 07 (2004), 29–53.

[17] Pirolli, P., & Card, S. Information foraging. *Psychological Review* 106, 4 (1999) 643-675.

[18] R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria: R Foundation for Statistical Computing.

[19] Rayner, K. Eye movements in reading and information processing: 20 years of research. *Psychological bulletin*, 124, 3 (1998), 372–422.

[20] Rayner, K. Eye movements and attention in reading, scene perception, and visual search. *Quarterly journal of experimental psychology*, 62, 8 (2009), 1457–506.

[21] Reader, W. R., & Payne, S. J. Allocating time across multiple texts: Sampling and satisficing. *Human–Computer Interaction* 22, 3 (2007) 263-298.

[22] Simola, J., Kuisma, J., Oörni, A., Uusitalo, L., & Hyönä, J. The impact of salient advertisements on reading and attention on web pages. *Journal of Experimental Psychology: Applied*, 17, 2 (2011), 174–90