**Mind the Links!**

**How Hyperlinks Influence Online Reading and Navigation:**

**An Eye Movement Study**

Hanna Martikainen

University of Turku

Faculty of Social Sciences

Psychology

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UNIVERSITY OF TURKU
Department of Psychology/Faculty of Social Sciences

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ABSTRACT
In this thesis, the eye movement methodology is used to explore the influence of hyperlinks and reading task on online reading in a navigable Web environment. The amount of research on hypertext reading is limited, and the understanding of hypertext processing is only developing. The previous eye movement studies conducted in a non-navigable web environment suggest that the hyperlinked words are not more difficult to process than unlinked words. The research also suggests that in the skim reading task, hyperlinked words are less likely to be skipped, and when they are fixated, they are processed more carefully than unlinked words. In this experiment, the possibility to click and navigate the hypertext made it possible to explore how the hyperlinks are processed in a more authentic Web environment. It was expected that the results from this experiment would be similar than those observed in previous studies: hyperlinked words would not be more difficult to process than unlinked words, and in the skim reading task, hyperlinked words would be processed more carefully than unlinked words. In the study design, thirty-two native English speakers read and navigated hypertext in a Wikipedia environment while their eye movements were recorded. The results indicate that hyperlinked words are not more difficult to process than unlinked words, but readers do focus on hyperlinked words. The results were not clear on whether the hyperlinked words were processed differently across the reading for comprehension and skim reading tasks. The early processing of hyperlinks was more careful compared to the unlinked words in the skimming task. Hyperlinks received more fixations, and their later processing was more careful than that of the unlinked words in both tasks. The results add to evidence that the visible form of hyperlink is not problematic for reading processes, but what words are selected as hyperlinks should be considered in user optimal web design. It is necessary to further explore reading and navigation on the web, with realistic tasks and in different web environments. It is also important to investigate how hypertexts are used in wider learning processes. Exploring how cognitive resources and individual differences influence hypertext processing is also crucial to find out how hypertexts can be made accessible and beneficial for all the users.

HEADINGS
Hypertext, hyperlinks, online reading, skim reading, eye movements, web design

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# 1. INTRODUCTION

This thesis explores the influence of hyperlinks and reading task on online reading in a navigable web environment. According to the global Internet usage statistics, we spend several hours a day browsing the web (Kemp, 2017), and a great amount of this time is spent reading hypertexts. Although reading online is a fundamental part of our daily life, cognitive processes in hypertext reading, and more specifically, the effects of hyperlinks on reading, have not been systematically studied. However, insight into how hyperlinks influence the human information processing is valuable, for instance for user-optimal web design.

## 1.1. The characteristics of hypertext

Hypertext is a dynamic text that consists of multiple pages, connected to each other through navigation tools and features. Unlike traditional linear texts, presented to the reader in the order that the author of the text has decided, hypertexts engage the reader to construct their own reading pathways (OECD, 2010). While the organisation of linear text is physically visible, only a part of the hypertext network is visible at one time, and often the reader does not know the extent of the text available (OECD, 2010).

An important hypertext navigation tool, and one of the most distinctive features of hypertexts, are hyperlinks, which allow the creation of multi-page hypertext networks (Conklin, 1987; OECD, 2010). Hyperlinks are used on almost all websites to provide readers acces to background, supplemental, or alternative information presented in context, increasing the possibility to integrate infomation from different sources (Chang & Chien, 2015). In the history of web design, it has been a common convention to display hyperlinks in blue (Naji, 2016).

## 1.2. Reading hypertext: a wider perspective

Since the amount of research on hypertext reading is limited, the exact understanding on how hyperlinks influence reading behavior and how hypertexts are processed, is still developing. The review of DeStefano and LeFevre (2007) suggests that hypertext reading places increased demands on working memory: it requires extra activities compared to linear text, such as increased decision-making processes as whether to follow a link or not, and interruptions to reading, for example when following a link to another window. Working memory only can process a limited amount of information simultaneously (Baddeley & Hitch, 1974), so the increased cognitive load can hinder nhreading processes, especially reading comprehension, where working memory may be central (Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014). Similarly, Scharinger, Kammerer, and Gerjets (2015) reported increased load on executive functions during hyperlink selection processes, observed as increased pupil dilation and decreased alpha frequency band power. Executive functions are also suggested to be central in reading comprehension (Sesma, Mahone, Levine, Eason, & Cutting, 2009). Based on these findings, the increased cognitive load required in hypertext reading would be disadvantageous for the text comprehension (DeStefano & LeFevre, 2007).

On the other hand, in the foreign language learning study of Nikolova (2004), hyperlinked words were reported beneficial for vocabulary acquisition and reading comprehension for average achieving students. In the study, French learners read a short text passage in French for general comprehension. In the text passage, there were 16 annotated words that were identified as “possibly difficult or unknown” for the participants. The readers could consult the annotated words as much as they wished: by clicking an annotated word, they could see the translation of each word. The readers were assigned to two groups: the annotated words were visible for one group, and invisible for the other group. The readers were also identified as high- or average-achieving students, based on their grades in French. The results showed that the visible hyperlinks were beneficial for vocabulary acquisition and reading comprehension for the average-achieving students. It was argued that the saliency of the hyperlinks helped average-achieving students to direct their attention toward the linked words and enhanced the retention of these words, leading to a better comprehension of the text presented in foreign language. For high achieving students, the hyperlinked words were not beneficial, nor a distraction. The suggested explanation for this was that the high-achievers have metacognitive skills that make external pointers unnecessary. They can direct their attention optimally without the aid of the hyperlinks, so adding them into the text does not improve their performance. The hyperlinks were a beneficial tool for average-achieving students, but did not influence the performance of the high-achievers.

The results of Nikolova (2004) indicate that the reader characteristics may influence the hypertext processing. In the study, hyperlinks were beneficial for average-achievers, but did not influence the performance of high-achievers in any way. However, it is important to note that the study was conducted in a simplified hypertext document. The structure of any modern web page is far more complex than the experimental stimuli of Nikolova, which consisted of a single text passage with annotated words. The hyperlinks simply provided access to the translation of the annotated words, whereas hyperlinks usually lead to a whole new web page with a large amount of content. It would be necessary to explore how individual differences affect more complex hypertext reading. Larger hypertexts are likely to require more demanding cognitive processing and place demands on working memory and executive functions, as discussed earlier (DeStefano & LeFevre, 2007; Scharinger et al., 2015). In tasks where intentional control and executive attention are needed, differences in working memory span have reported to become apparent, leading to a better performance of individuals with high working memory capacity (Unsworth & Engle, 2005). The increased cognitive load in hypertext reading may be especially detrimental for readers with low working memory capacity.

The studies reviewed above are important in building the wider understanding on hypertext processing. From these studies, it can be concluded that hypertext reading may place increased demands on working memory and executive functions, which can be disadvantegous for reading comprehension. On the other hand, in a simple hypertext document, hyperlinks may be beneficial for some students in language learning task. If these results are connected to a wider context in cognitive psychology, it can be suggested that individual differences in cognitive capacity, especially in working memory, are likely to influence hypertext processing.

The next chapters will focus on reviewing the current knowledge of hypertext processing on a more detailed level. The focus is on a few experiments that have used eye movement methodology to study how hyperlinks are processed.

### 1.3. Hyperlinks, reading processes and eye movements

Eye tracking is widely used, well established methodology in experimental reading research (Radach & Kennedy, 2004). The benefit of the methodology is that it provides a detailed picture of the moment-to-moment processing of text information while not posing extra task demands to the reader (Rayner, 1998). In the hypertext research, the eye tracking is a novel methodology, which only have been used in a few studies. These experiments are the first to explore detailed cognitive processes in hypertext reading.

Fitzsimmons, Weal, and Drieghe (2013) used the eye movement methodology to investigate if the blue colour influences text readability. The question is important, as presenting text in blue is a common way to mark a hyperlink (Naji, 2016). It has been argued that the blue hyperlink colour would be a poor design choice that reduces the hyperlink readability, since only two percent of the cone cells on the retina are blue-sensitive (Nielsen, 1999; Galitz, 1997). If a blue word in black text hinders reading, then only the presence of blue hyperlinks in the text would negatively affect reading processes. In the study of Fitzsimmons et al. (2013), participants read sentences of one text line. The sentences were presented in black, except one word that was presented either in black, blue, red, green, or grey. To explore how the sentences were processed, several eye movement measures were analysed, including *first fixation duration* (the duration of the first fixation on the target word), *single fixation duration* (the fixation duration when the reader makes only one fixation on a word during the first pass reading), *gaze duration* (the sum of all fixations on a word before making a saccade to another word), and *go-past times* (the accumulated time from the first fixation on the target word until the first fixation to the right of the target word, including the regressions). There was no difference in these eye movement measures between different colours, suggesting also that blue colour in black text does not hinder text readability. Therefore, presenting a hyperlink in blue would not be disadvantageous for reading.

Even if the blue words in the black text would not reduce text readability, the blue text could attract the attention of the reader and therefore be a disruption. In eye movement measures, this could be seen in *skipping probability,* which represents the probability that the reader skips the target interest area on the first pass reading. In the colour experiment of Fitzsimmons et al. mentioned above, the coloured words did draw the attention of the readers: the coloured words were less likely to be skipped compared to uncoloured words, suggesting that the saliency of the colours drew the attention of the reader to the word. Fitzsimmons et al. (2013) conducted another experiment investigating if the saliency of the blue text in the middle of the black text attracts the attention of the reader. In the experiment, the participants read edited Wikipedia articles, where target words were presented either in blue or black. The other text was presented in black. There were no difference in the skipping probability between the blue and black target words. It is interesting that the salience effect observed for the coloured words in skipping probability was not present in this experiment. A likely explanation for the result is that the readers perceived the blue words in Wikipedia environment as hyperlinks. It has been discussed earlier that experienced Internet users may have formed automatic attention response to blue text that indicates the presence of a hyperlink (Pearson & van Schaik, 2003; Nielsen, 1999). The results of Fitzsimmons et al. (2013) suggest that when a word is perceived as a hyperlink, it does not attract the attention of the reader in the same way than a coloured word does.

In the same Wikipedia experiment, Fitzsimmons et al. (2013) also observed if the blue hyperlinks were more difficult to process than unlinked words. They explored early eye movement measures (first fixation duration, single fixation duration and gaze duration) between the black and blue target words. There was no difference in these measures between the target words. This result has later been replicated (Fitzsimmons, Weal, & Drieghe, 2014). If early eye movement measures represent automatic, bottom-up response to the target words, rather than willed top-down processing, it could be derived from these results that a hyperlinked word in the text is not more difficult to process than an unlinked word.

In conclusion, the studies of Fitzsimmons et al. (2013, 2014) suggest that the blue hyperlink colour does not hinder the text readability, that the salience of the blue hyperlink does not disrupt reading, and that the hyperlinked words are not more difficult to process than unlinked words. In these experiments, however, the readers were not able to click the hyperlinks and navigate the experimental Wikipedia. In the current experiment, the readers are additionally given the possibility to click the hyperlinks and navigate the articles. This will make it possible to explore how the hyperlinks are processed in a more naturalistic Web environment, where the words presented in blue are actual, clickable hyperlinks.

## 1.4. Hyperlinks and reading strategy

Hypertext reading is likely to involve specific reading strategies. As there is an expansive amount of information available online, the reader usually does not have time to read all of it. Indeed, time online is usually spent on browsing, scanning, keyword spotting, and one-time reading, while less time is spent on in-depth reading, and concentrated reading (Liu, 2005). This kind of reading strategy is called skim reading. It is around twice as fast than normal reading, and readers are more likely to skip over multiple words than when reading normally (Just & Carpenter, 1987; Fitzsimmons, Weal, & Drieghe, 2014). When readers do fixate a word, the fixation times are shorter than in normal reading (Just & Carpenter, 1987; Fitzsimmons et al., 2014).

Skim reading has been reported to hinder comprehension compared to normal reading, but it has been suggested to be an effective strategy to gain important information from the text in limited time (Just & Carpenter, 1987; Duggan & Payne, 2009; Fitzsimmons et al., 2014). In general, there is evidence that when the reading speed increases, the text comprehension is reduced (Carver, 1984), but it has also been suggested that when readers have to read faster, they are able to focus on the relevant, important information in the text (Masson, 1982; Reader & Payne, 2007). The experiments of Duggan and Payne (2009) and Fitzsimmons et al. (2014) suggest that this is exactly what skim readers do. They are likely to use the satisficing strategy, a concept from information foraging research, according to which readers are constantly monitoring their information gain (Reader & Payne, 2009). Readers´ decision to keep reading a part of text or to move forward in the text is based on this gain. When the amount of information they are getting in a certain part of a text decreases, readers quickly move forward, trying to go through the text as efficiently as possible without losing comprehension.

Fitzsimmons et al. (2014) explored how hyperlinks influence word skipping when skim reading. The results indicated that readers are less likely to skip linked words and to fixate unlinked words when they skim read. As readers tend to fixate the hyperlinked words, they may use them as markers of important information that assist them to skim through the text efficiently. The same effect was not present in normal reading.

The study of Fitzsimmons et al. (2014) also suggests that when skim readers fixate a linked word, they process them fully. This was observed as a present frequency effect for the linked words, but not for the unlinked words, in the skim reading condition. In the reading for comprehension condition, the frequency effect was observed for both linked and unlinked words. Word frequency effect means that higher frequency words (words that are commonly used in a language) are fixated less and for shorter time than low frequency words (words that uncommonly occur in a language), since supposedly more automatic and less demanding lexical processing of high frequency words is typically faster than that of low frequency words (Inhoff & Rayner, 1986). In the experiment of Fitzsimmons et al. (2014), the hyperlinked low frequency words had significantly longer go-past times and total reading times in the skim reading task, compared to high frequency linked words, and both high and low frequency unlinked words. This effect was only present in the late eye movement measures, suggesting that when processing linked low frequency words, readers make regressive eye movements, re-evaluating the preceding content and integrating the word into it. Skim readers seemed to focus on fixating and processing the linked words, implicating they may have used hyperlinks as anchors of the important information. The missing frequency effect for the unlinked words during skim reading indicates that the readers did not process unlinked words to the same degree than linked words. If readers only process linked words in the skim reading task, it suggests that they give linked words more value than for unlinked words while aiming to gain information as efficiently as possible. Since the frequency effect was observed for both linked and unlinked words in the comprehension task, readers processed the linked and unlinked words in an equal thoroughly way. The difference between the tasks suggests that there is a difference in how hyperlinks are processed between normal reading and skim reading: when readers need to skim read, they focus on the linked words and are more likely to ignore the unlinked words.

The study of Fitzsimmons et al. (2014) was the first experiment using eye movement methodology to explore the effects of hyperlinks and reading task on hypertext processing. The results from the experiment suggest that skim readers are less likely to skip linked words and to fixate unlinked words. Also, skim readers seem to focus on the linked words and process them more carefully than unlinked words, which implicates that skim readers may use hyperlinks as anchors of important information. In the experiment of Fitzsimmons et al. (2014), however, the readers did not have the possibility to click the hyperlinks and navigate the hypertext. The current experiment is identical with the experiment of Fitzsimmons et al. (2014), apart from the additional possibility to click the hyperlinks and navigate the Wikipedia environment. The navigable environment will make it possible to explore how the hyperlinks are processed in a more naturalistic hypertext, which is suggested to require more demanding cognitive processing and place demands on working memory and executive functions (DeStefano & LeFevre, 2007; Scharinger et al., 2015).

## 1.5. Reseach questions and hypotheses

The purpose of the present experiment is to explore the influence of hyperlinks and reading task on online reading in a navigable Web environment. Specifically, it is interesting to see if the effects perceived in the previous studies in a non-navigable Web design would be still found in an experiment, where readers are additionally able to click the hyperlinks and navigate the hypertext. Although the data gathered in the current experiment would allow several different analyses, in this thesis the focus is in comparison of the results from this experiment with the results of previous studies exploring the task effects and word type effects on hypertext processing.

In previous studies, the hyperlinked words were not more difficult to process than unlinked words in the reading for comprehension task. In the skim reading task, hyperlinked words were less likely to be skipped, and when they were fixated, they were processed more carefully than unlinked words. In this experiment, the possibility to click and navigate the hypertext will make it possible to explore how the hyperlinks are processed in a more authentic Web environment, where the words presented in blue are actual, clickable hyperlinks. It is also possible to observe how the expected more demanding cognitive processing, and increased demands on working memory and executive functions will influence the hypertext processing.

Based on the research reviewed above I expected that:

1) During reading for comprehension, a hyperlinked word is not more difficult to process than an unlinked word, observed as no difference in the early eye movement measures (first fixation duration, single fixation duration and gaze duration) during the first pass reading. In this hypothesis, it is assumed that difficulty in word processing would be seen in early lexical processing, therefore only early measures are used.

2) When readers skim read, the late processing of the hyperlinked words is more careful than that of unlinked words. The readers are less likely to skip the hyperlinked words, the linked words will receive more fixations and the late eye movement measures (go-past times and total reading times) will be longer for the linked words, compared to the unlinked words.

# 2. METHOD

## 2.1. Participants

Thirty-two native English speakers (16 women, $M_{age}$ = 24.7 years, age range: 18–43 years) took part in the experiment. Only participants who had normal or corrected-to-normal vision and who did not have reading difficulties were included in the study. The participants were students or staff members in University of Southampton, England. Participants were recruited by posting flyers around the university campus, sending e-mails to students and by personal contact. For their time and effort, the participants were rewarded with £6 per hour or 6 study credits.

## 2.2. Equipment

Eye movements were recorded with an SR-Research Eyelink 1000 system running at 1000Hz (more details can be found on http://www.sr-research.com/eyelink1000.html). During recording, the participants sat at a computer display terminal. Their head was stabilised with a chin rest to reduce head movements affecting the recording quality. The size of the screen was 23 inches and the refresh rate was set as 100hz. The display was adjusted to be 73 centimeters from the participant's eye, at a distance where three characters equal approximately 1° of visual angle. Viewing was binocular, but eye movements were only recorded from one eye. To move forward and backward in the Wikipedia environment and to answer comprehension questions, the participants used a mouse and keyboard buttons.

## 2.3. Materials

To explore the reading processes in a realistic Web environment, there was a need to create a clickable and navigable experimental environment, where the traditional eye tracking methodology and the EyeLink system could be used. To simulate a naturalistic online clicking and navigation task, it was necessary that the Web environment, with article pages and hyperlinks, was extensive enough to create a feeling of a navigable, unlimited space. Yet, the experimental control needed to be considered: it was essential that the participants read and navigated the articles that contained target words.

To ensure that the web environment was extensive enough, but also that the experimental control was retained, four subsections of Wikipedia were created. By dividing the experiment into four sections, it was possible to limit the navigation area and to ensure that the participants did interact with the target words. Additionally, by creating four subsections, instead of one expansive section with exponentially growing number of experimental articles, it was possible to reduce the number of articles that needed to be created.

The structure of each subsection consisted of four levels (see Figure 1). Each of the four subsections had their unique starting article, which represented the level one. Each hyperlink in the first article lead to another article, which also contained its hyperlinks, leading to other articles with their hyperlinks. The first article in each subsection contained ten hyperlinks on average, and the articles that opened after clicking these hyperlinks also typically contained ten hyperlinks. In the following articles, the number of hyperlinks varied depending of the article length. On the level four, most of the hyperlinks brought the participant back to a lower level article. There were also some articles without hyperlinks to restrict the size of the Wikipedia section. After reading one of these dead-end articles, the participants needed to press the back button to move to the previous article, where they had access to other articles via hyperlinks.

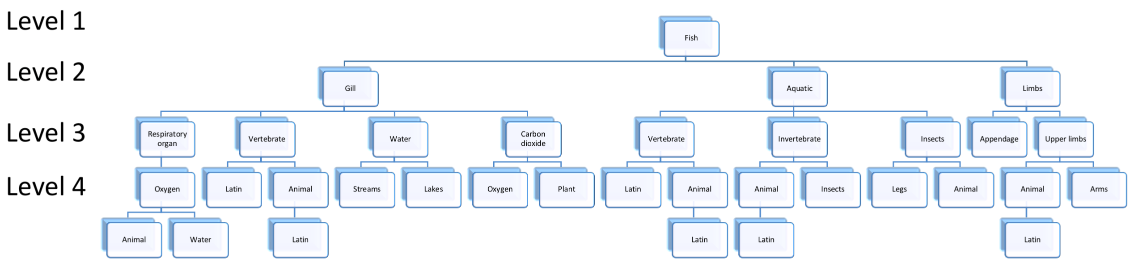


***Figure 1***. A simplified example of a Wikipedia subsection structure with four levels. For clarity, all the hyperlinks at the level four are not illustrated in the model (Fitzsimmons, 2017, p. 172).

The stimuli consisted of 843 edited Wikipedia articles (see Figure 2). The articles were created by selecting existing Wikipedia articles on neutral topics, and inserting into them experimental sentences containing a target word. The created experimental sentences fitted in with the existing article. Apart from this modification, the articles were identical to the original versions, including the words that were hyperlinked. Article length varied between two and twelve text lines and one and fourteen sentences.

On average, there were 5.44 sentences in the articles. The characters in the articles were presented in 14pt black monospaced Courier font. Characters were lowercase, except when capitals were appropriate.

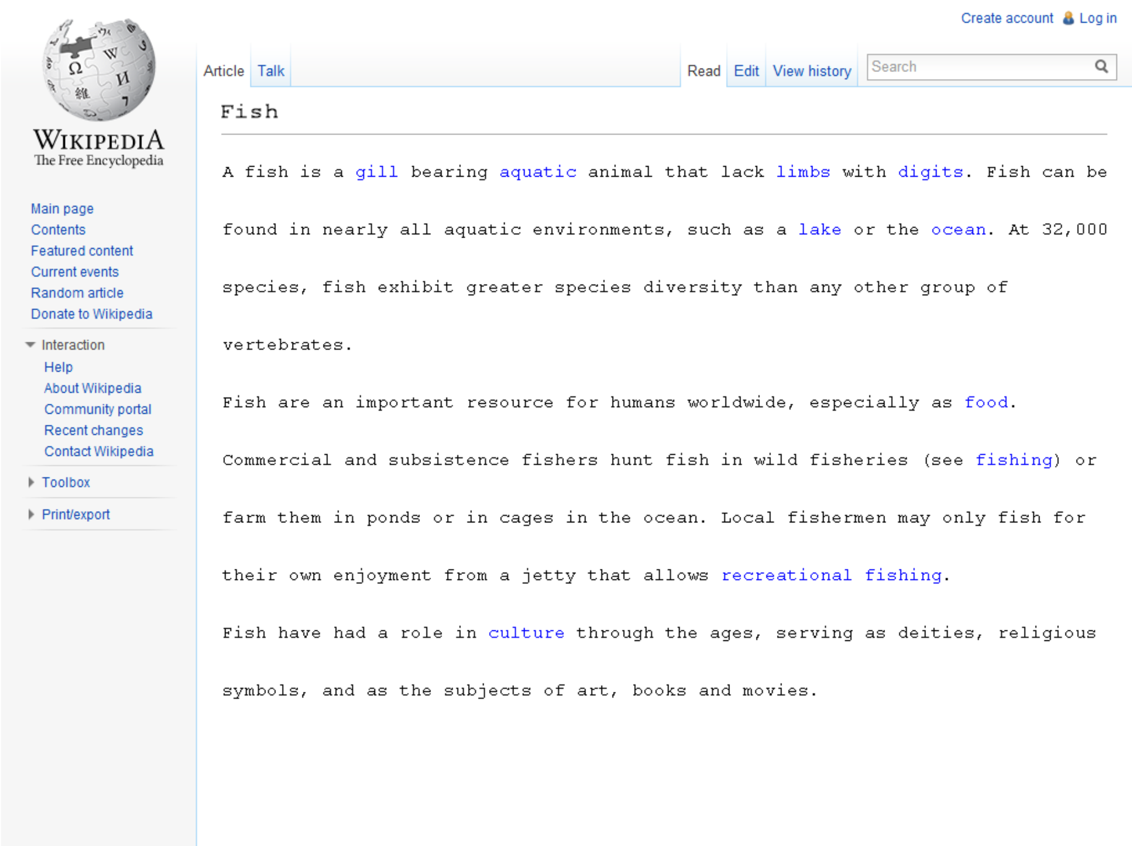


***Figure 2.*** An example of an edited Wikipedia article used in the experiment (Fitzsimmons, 2017, p. 181).

In total, there were 326 Wikipedia articles containing target words and 517 articles without targets. Of the target articles, 191 articles contained one target word, 124 articles contained two target words, and 11 articles contained four target words. In total, there were 472 target word pairs used in the experiment. The target words in the articles were either displayed in blue or black to denote if the word was a hyperlink (blue) or not (black). If the hyperlink had already been visited, the target word was displayed in purple.

For each experimental sentence, only one target word was used. The location of the target words varied, but in none of the sentences they were the first or the last word of the line. The target words were nouns and their length varied between four and seven characters. The average length was 5.12 characters. The word frequencies were extracted from the Hyperspace Analogue to Language (HAL) corpus, which consists of approximately 131 million words, gathered across 3000 Usenet newsgroups (Burgess & Livesay, 1998). The average log transformed HAL frequency for the target words was 9.55, and it ranged between 3.33 and 12.88.

For more detailed information on the material design, see Fitzsimmons (2017).

## 2.4. Procedure

The task in the experiment was to read and navigate edited Wikipedia articles, created to simulate reading and navigating on the Web. Each article represented one trial. In the beginning of the experiment, participants were given an information sheet and a verbal description of the experimental procedure, and informed that they would be reading articles on a monitor while their eyes would be tracked. They were told they could click the hyperlinks and navigate the Wikipedia articles. Before the currrent experiment, the participants completed another short single line reading experiment not reported in this thesis.

The experiment was divided into four sessions. In the first two sessions, the participants were asked to read the articles normally for comprehension and to answer a comprehension question concerning the article, if it was presented after reading it. For each of the two reading for comprehension sessions, the participants were allowed to visit 10 unique articles. For the sessions three and four, the task was to skim read the articles, so the participants were asked to read faster, as if they were revising for an exam. They still needed to answer comprehension questions, but they were told they did not need to be too concerned about correctly answering all the questions. For the skim reading task, the participants visited 20 unique articles for each of the two sessions. The number of the visited articles was higher in the skimming task than in the comprehension task to obtain a comparable number of fixations on target words in the two tasks, as skimming was expected to induce more word skipping. In total, the experiment lasted approximately 60 minutes.

At the beginning of each article the participants first had to look at a fixation point on the left side of the screen, where the first sentence of the article started. When a stable fixation on the fixation point was registered, the article was displayed. This was to ensure that the participants started reading at the beginning of the article and did not pick up any information from the article before starting. Participants were instructed to first read or skim read each article, before selecting a hyperlink and navigating to another article.

When the participants finished reading an article, they selected one of the hyperlinks and navigated to the next article by clicking the hyperlink. They were also able to go back to any of the previous articles by pressing the designated back button on the keyboard. Occasionally the participants needed to answer a comprehension question on the article they had finished, before having access to the next article they had chosen. When a participant clicked a hyperlink, they either moved right to the next article, or first answered a comprehension question that appeared on the screen. The comprehension questions were closed True–False questions and the participants answered them by clicking the appropriate response on the screen with the mouse cursor. After the question the next article, chosen previously by the participant by clicking one of the hyperlinks or by pressing the "back" button, was displayed.

The aim of the comprehension questions was to control that the participants were really reading and comprehending the text and to measure the level of comprehension across the tasks. A question was presented after reading an article if it had a question attached to it. On average the questions were presented on 45% of articles. If the participant had visited an article with a comprehension question before, the question was not displayed again.

## 2.5. Design

The design was a 2 (Task Type: Normal, Skimming) x 2 (Word Type: Linked, Unlinked) within-participant design. All the participants started the experiment with reading for comprehension task (Task Type: Normal). For this task type, they read 2x10 articles. After this they continued with skim reading task (Task Type: Skimming), where they read 2x20 articles. The order of the Task Type was not counterbalanced out of concern that the normal reading sections would be influenced by first having to skim read. The participants were not told they were going to skim read until the skim reading part was due to begin, to ensure they read the first 20 articles normally.

The first article that a participant saw in each of the four sessions was controlled by the experimenter, and the order of the first articles in the conditions was counterbalanced across participants. The participants started reading with a given first article but were then free to navigate the articles as they wished, so the article order within the sections was not blocked. The combination of articles and their sequence was unique for each participants as the participants themselves chose their navigation path in Wikipedia, except from the given first article. For this reason, the number of observed target words varied between participants.

# 3. RESULTS

## 3.1. Data cleaning

Trials with tracking loss were removed prior to analysis: the trials with less than three fixations were eliminated, as well as the trials with deficient calibration, and the trials with ascending or descending eye movements towards the end of the sentence.

Fixations shorter than 80 ms 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 (5.89% of the total dataset). An interest area was drawn around each target word. The interest area is the size of the target word including the space preceding it. The following analyses are conducted using the fixations that landed on the target word, within the interest area drawn around it. The skipping probability analysis is an exception: it is conducted based on the observed skipping rates.

Before the analyses, the data that were more than 2.5 standard deviations from the mean for a participant within a specific condition were removed (<0.99% of the dataset). Data loss affected all conditions similarly (mean data loss per condition was 1.24%, and the loss ranged between 0.35% –2.44% in each condition).

## 3.2. Eye movement measures

Several different eye movement measures on target interest area were computed and analysed.

*Skipping probability* is the probability that the reader skips the target interest area on the first pass reading and does not fxate it. Skipping probability is calculated by dividing the frequency of the target words that are not fixated by the number of all target words.

*Target fixations* represent the number of fixations made on the target interest area.

*First Fixation Duration* is the duration of the first fixation on the target word, regardless of whether it is the only fixation or the first of multiple fixations. First fixation duration measures the early effects of processing a word (Rayner & Duffy, 1986).

*Single fixation duration* is computed when the reader makes only one fixation on a word during the first pass reading. As first fixation duration, it measures the early effects of word processing.

*Gaze duration* represents the sum of all fixations on a word before making a saccade to another word.

*Go-Past Time* is the accumulated time from the first fixation on the target word until the first fixation to the right of the target word. It includes the regressions made before moving past the target word and thus measures the late effects of word processing: difficulties in text processing and specifically in word integration can increase the go-past time measure (Rayner, 1998).

*Total reading time* is the sum of all fixation durations on the target word, during the first pass reading or later. Traditionally, the total reading time includes all the time used to read and re-read the text, and increased total reading times usually indicate difficulties in integrating words or sentences. In the current study, however, the participants were navigating the text. Thus, the total reading time additionally represents the time that the participant used making the decisions that the hyperlinks involve, such as whether to click a hyperlink or not. Separating this decision-making time from the traditional total reading time would be difficult, but it can be assumed that the total reading time for the unlinked words represent the traditional measure, and the increased total reading time for linked words additionally includes the time used making decisions.

## 3.3. Data analysis

The eye movement measures were analysed with a repeated measures ANOVA. The design was 2 (Task Type: comprehension vs. skimming) x 2 (Word Type: unlinked vs. linked) within-participant design. The counterbalancing factor of the first article assigned to the readers (4 levels), which was controlled by the experimenter, was included in the analysis as a between-subjects factor to reduce the error term. Significant interactions were followed up with paired samples t-tests, using Bonferroni corrections.

## 3.4. Results

The descriptive statistics (means and standard deviations) for all the eye movement measures as a function of reading task and word type are presented in Table 1.

**Table 1.** *Descriptive statistics for the eye movement measures as a function of Task Type and Word type.*

| | | Task Type | | | |
|---|---|---|---|---|---|
| | | Comprehension | | Skimming | |
| Measure * | Word type | M | SD | M | SD |
| Skipping probability | Linked | 13 | 13 | 16 | 12 |
| | Unlinked | 21 | 20 | 17 | 20 |
| Target fixations | Linked | 2.41 | .78 | 1.89 | .37 |
| | Unlinked | 1.53 | .31 | 1.20 | .25 |
| First fixation duration | Linked | 208 | 24 | 216 | 29 |
| | Unlinked | 217 | 32 | 197 | 33 |
| Single fixation duration | Linked | 221 | 51 | 223 | 41 |
| | Unlinked | 228 | 53 | 197 | 38 |
| Gaze duration | Linked | 287 | 76 | 268 | 56 |
| | Unlinked | 276 | 54 | 219 | 43 |
| Go-past time | Linked | 306 | 102 | 271 | 79 |
| | Unlinked | 275 | 54 | 216 | 50 |
| Total reading time | Linked | 549 | 184 | 453 | 115 |
| | Unlinked | 318 | 79 | 231 | 47 |

* Skipping probabilities expressed in percentages, target fixations in frequencies, all the other measures in milliseconds.

**Skipping probability**

Task type or Word type did not have significant main effects on skipping probability (Task type $F_{1,28}$=.079, $p$=.78, $n_p^2$=.003, Word type $F_{1,28}$=2.80, $p$=.105, $n_p^2$=.091). There was a marginal Task type x Word type interaction ($F_{1,28}$=3.04, $p$=.092, $n_p^2$=.10) and further analysis revealed that in the comprehension task linked words were less likely to be skipped than unlinked words (t(31)=-2.42, p=.042, $d$=-.43). In the skimming task there was no difference in skipping probability between linked and unlinked words (t(31)=-.18., p=1, $d$=-.032).

**Target fixations**

Task type and Word type had significant main effects on target fixations (Task type $F_{1,28}$=32.36, $p$<.001, $n_p^2$=.54, Word type $F_{1,28}$=78.83, $p$<.001, $n_p^2$=.74). As can be seen in the Table 1, more fixations were made in comprehension task than in skimming task, and linked words received more fixations than unlinked words. Task type x Word type interaction was not significant ($F_{1,28}$=1.74, $p$=.20, $n_p^2$=.06).

**First fixation duration**

Task type or Word type did not have significant main effects on first fixation duration (Task type $F_{1,27}$=2.36, $p$=.136, $n_p^2$=.080, Word type $F_{1,27}$=1.61, $p$=.215, $n_p^2$=.056). There was a significant Task Type x Word Type interaction on first fixation duration ($F_{1,27}$=10.90, $p$<.003, $n_p^2$=.29), see Figure 3. Subsequent pairwise comparisons showed that in skimming task first fixation durations for unlinked words were significantly shorter than for linked words (t(30)=3.65, $p$=.002, $d$=.66). The same effect was not present in comprehension task where there was no significant difference in first fixation durations between linked and unlinked words (t(30)=-1.18, p=.50, $d$=-.21).

**Single fixation duration**

Task type had a marginal main effect on single fixation duration ($F_{1,24}$=3.34, $p$=.080, $n_p^2$=.12). There was no main effect of Word type ($F_{1,24}$=1.02, $p$=.32, $n_p^2$=.04). Task type x Word type interaction effect was significant ($F_{1,24}$=6.83, $p$=.015, $n_p^2$=.22) and was qualified by a significant Word type effect in the skimming task, where unlinked words were fixated for shorter time than linked words (t(27)=3.16, $p$=.008, $d$=.60), see Figure 3. In the comprehension task there was no difference between linked and unlinked words (t(27)=-.56, p=1, $d$=-.11). Although in the comprehension task the fixation times for linked and unlinked words were approximately the same, in skimming task the unlinked words were fixated for much shorter time than linked words, which explains the Task type x Word type interaction effect.

**Gaze duration**

Task type had a significant effect on gaze duration ($F_{1,27}$=28.65, $p$<.001, $n_p^2$=.52). Word type also had a significant effect on gaze duration ($F_{1,27}$=22.30, $p$=.003, $n_p^2$=.29). There was also a significant Task type x Word type interaction effect ($F_{1,27}$=6.50, $p$=.017, $n_p^2$=.19), explained by significantly shorter gaze durations for unlinked words than for linked words in the skimming task (t(30)=4.72, $p$<.001, $d$=.85), see Figure 3. Although in the comprehension task there was no significant difference between linked and unlinked words (t(30)=-.771, p=.45, $d$=-.14), the difference between them in the skimming task was great enough to arise the Task type x Word type interaction effect.

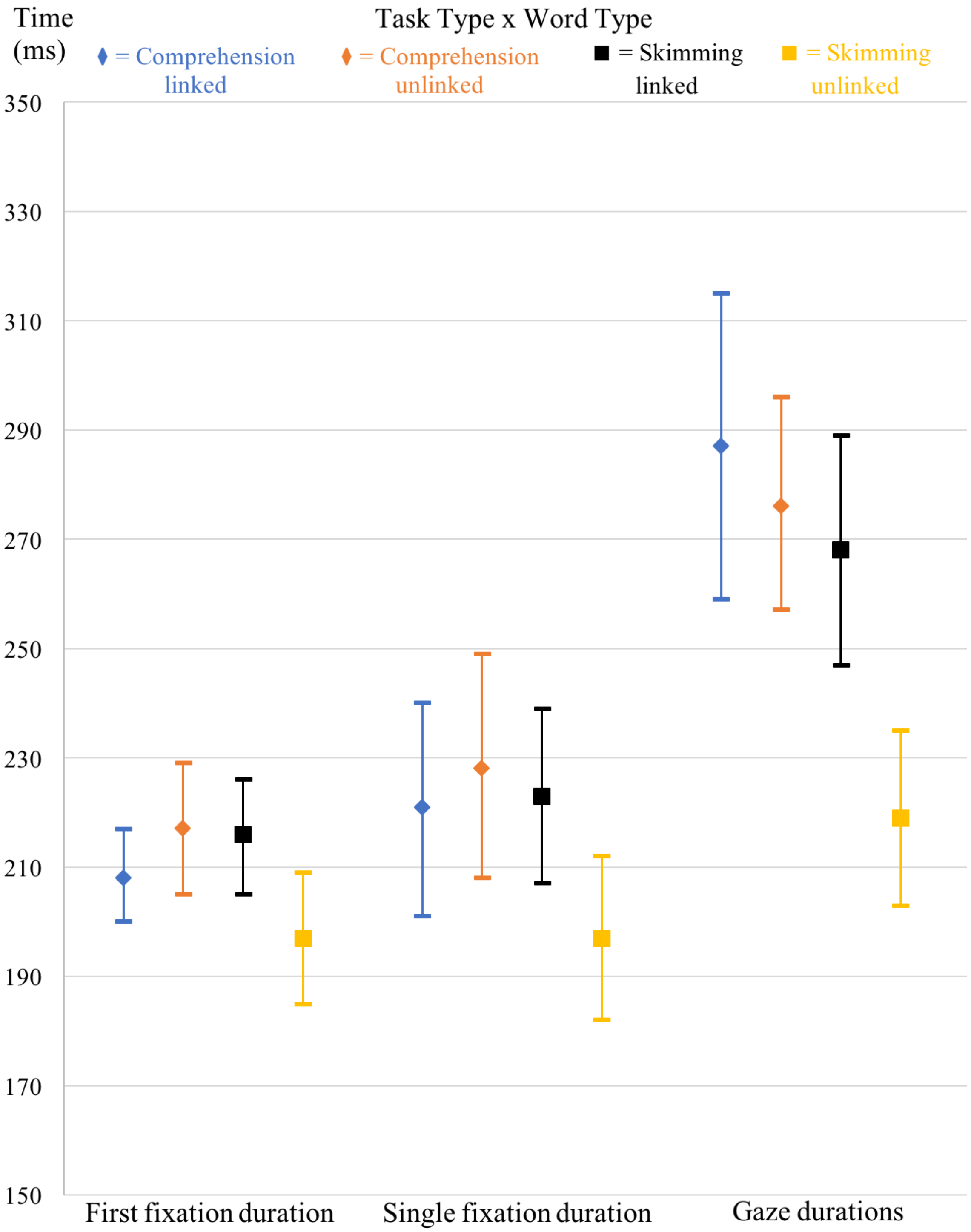


**Figure 3.** *Means for first fixation durations, single fixation durations, and gaze durations in four conditions. Error bars represent 95% confidence intervals.*

**Go-past time**

Task type had a significant main effect on go-past times ($F_{1,26}$=21.39, $p$<.001, $\eta_p^2$=.45). Word type also had a significant effect on go-past times ($F_{1,26}$=12.43, $p$=.002, $\eta_p^2$=.32). As can be seen in the Table 1, reading times were shorter in skimming task compared to comprehension task, and for unlinked words compared to linked words. There was no significant Task type x Word type interaction ($F_{1,26}$=1.50, $p$=.23, $n_p^2$=.06).

**Total reading time**

The analysis of the total reading time revealed significant main effects of Task type ($F_{1,28}$=36.28, $p$<.001, $n_p^2$=.56) and Word type ($F_{1,28}$=99.53, $p$<.001, $n_p^2$=.78). Target words were read significantly faster in skim reading task compared to comprehension task, and unlinked target words were read significantly faster than linked words (see Table 1). The Task type x Word type interaction was not significant ($F_{1,28}$=1.74, $p$=.20, $n_p^2$=.06).

# 4. DISCUSSION

The purpose of the experiment was to explore the influence of hyperlinks and reading task on online reading in a navigable Web environment. Specifically, it was interesting to compare the results with the results from previous studies, conducted in a non-navigable Web design.

Hyperlinked words were less likely to be skipped than unlinked words in the comprehension task, but in the skim reading task there was no difference in skipping between linked and unlinked words. When it comes to the fixations made on target words, linked words received more fixations than unlinked words, and more fixations were made in comprehension task than in skimming task. In the skimming task, the early eye movement measures (first fixation durations, single fixation durations, and gaze durations) were shorter for unlinked words than for linked words. In the comprehension task, there were no difference in these fixation durations between linked and unlinked words. The late measures (go-past times and total reading times) were longer in the comprehension task than in skimming task, and longer for linked words than for unlinked words.

## 4.1. Findings

The first hypothese was that in the reading for comprehension condition, there would not be difference between linked and unlinked words in the early eye movement measures (first fixation duration, single fixation duration and gaze duration) during the first pass reading. This would indicate that a hyperlinked word is not more difficult to process than an unlinked word, as Fitzsimmons et al. (2013, 2014) suggested. Indeed, there was no significant difference in first fixation durations and single fixation durations between linked and unlinked words, confirming the earlier results that hyperlinked words are not more difficult to process than unlinked words. Compared to the earlier experiments of Fitzsimmons et al. (2013, 2014), this experiment additionally allowed the participants to click and navigate the hypertext. Despite this, the results were similar compared to the earlier results of Fitzsimmons et al. (2013, 2014).

However, there was an interaction between reading task and word type: in the skimming task, linked words received significantly longer first fixation durations, single fixation durations and gaze durations than unlinked words. The result suggests that when readers skim read, they give hyperlinks special value. It is interesting that the same effect was not present in the reading for comprehension task, even when in both tasks readers were navigating using hyperlinks, and therefore, they needed to direct their attention toward the links. Possibly the result indicates that when, in the skim reading task, readers know that they do not have time to read the text fully, they decide to focus on the linked words. If the similar early fixation times in the reading for comprehension task can be interpreted as the ease of processing of both hyperlinked and unlinked words, the difference between linked and unlinked words in the skim reading task is not likely to indicate that the increased reading speed would make the hyperlinked words more difficult to process. Rather, it could indicate that skim reading involves a different reading strategy, in which hyperlinks are perceived worth focusing. The differences in the early eye movement measures between linked and unlinked words in the skimming task can reflect an automatic response to the hyperlinked words (Pearson & van Schaik, 2003; Nielsen, 1999).

The second hypothese was that in the skim reading task, hyperlinked words would be processed more carefully than unlinked words. I expected that during skim reading, the linked words would be less likely skipped, there would be more fixations on the linked words, and the late eye movement measures (go-past times and total reading times) would be longer for the linked words, compared to the unlinked words.

There was no overall difference in skipping probability between reading for comprehension and skimming tasks, but there was a marginal interaction between reading task and word type: in the comprehension task, hyperlinked words were less likely to be skipped than unlinked words. In the skimming task, there was no difference in skipping between linked and unlinked words. This is an interesting result as it contradicts the study of Fitzsimmons et al. (2014) where skim readers, but not normal readers, were less likely to skip linked words and less likely to fixate unlinked words. The possibility to navigate the text may have caused the difference between these two studies, indicating that a navigable text involves more skipping in reading for comprehension task, and less skipping in the skimming task. However, it is interesting that even though the results from early eye movement measures suggest that the skim readers focus on the hyperlinked words in the first pass reading, this is not seen in the skipping probability: skim readers may skip hyperlinks as often as they skip the unlinked words. This is interesting, since increased fixation times may often co-occur with reduced skipping rates (eg. Rayner, Slattery, Drieghe, & Liversedge, 2011). It needs to be emphasized, however, that the Task type x Word type interaction in skipping probability was only marginal.

When it comes to the fixations made on target words, linked words received more fixations than unlinked words both in reading for comprehension and skim reading tasks. Also, in the comprehension task both linked and unlinked words received more fixations than in skimming task. Thus, the expected effect that hyperlinked words would receive more fixations, was present in both tasks, not only in the skim reading task. This is a logical result, and adds to evidence that the hyperlinked words are processed more in depth than unlinked words when we read online. The results also indicate that the skim reading strategy involves less fixations and in-depth processing, as has been suggested before (Just & Carpenter, 1987; Liu, 2005).

The readers used more time processing the target words in the comprehension task than in the skimming task, seen as longer go-past times and total reading times on target words in the comprehension task. Readers also processed linked words more carefully than unlinked words, both in reading for comprehension and skim reading task. When readers process the hyperlinked words, they make more regressions, evaluating the hyperlink and the context, trying to integrate information. Additionally, they use time gaining information and making the decision on whether the hyperlink is worth following or not, which can be seen especially in total reading times. It is possible that the increased total reading times for the hyperlinked words simply reflect the decision-making processes that the hyperlinks involve. However, the longer go-past times for the linked words in both tasks indicate that readers focused on the linked words already on the first pass reading, not only in the skimming task, but also in the comprehension task. Readers seem to give hyperlinks special value, even when they have more time to read the text. Possibly, knowing that hyperlinks provide access to additional information and that they can be used for navigation keeps readers focused on them already on the first pass reading.

In conclusion, it seemed that hyperlinked words are not more difficult to process than unlinked words, but readers do give them special value. Skim reading strategy involved less fixations and less in-depth processing than reading for comprehension, but the results were not clear on whether the hyperlinked words were processed differently across the two tasks. Hyperlinks were less likely to be skipped than unlinked words in the comprehension task, but their early processing was more careful compared to the unlinked words in the skimming task. Hyperlinks received more fixations than unlinked words both in comprehension and skim reading tasks, and in both tasks their later processing was more careful than that of the unlinked words.

### 4.2. Limitations

The current study had some limitations. Firstly, the chosen statistical analysis, the repeated measures ANOVA, only examined the between-subjects variation. Using linear mixed models would have had the advantage of analyzing also the variation between the test items, the target words (Baayen, Davidson, & Bates, 2008). Item analysis with the ANOVA was not convenient, as the participants did not see the same targets, but freely navigated creating their own reading paths. Therefore, the word frequency effects were not explored in this thesis. However, item variation, including the word frequency variation, is a part of the between-subjects variance. Despite of this, the observed effects were clear enough to be perceived.

Secondly, the experimental design was not fully controlled. To simulate a realistic navigation task, it was necessary that the web environments used in the experiment, large experimental Wikipedia subsections, gave the readers an impression of an expansive, unlimited space. For the same reason, the readers were given the freedom to construct their own reading and navigation paths by selecting the articles by themselves. Due to this, some experimental control was lost. The experiment was not a classical experimental study where all the readers read the same target words in all different conditions. However, there was enough experimental control to receive comparable measures. Additionally, the created materials and the experimental design introduced a new method for online reading and navigation research. In the future designs, the issues concerning the experimental control can be further addressed.

Thirdly, the order of the Task Type in the experiment (reading for comprehension or skim reading) was not counterbalanced. This was done out of concern that the normal reading would be influenced by first having to skim read. To ensure that the participants read the first 20 articles normally, they were told about the skim reading task only before the task started. However, the skim reading task could also have been influenced by first having to read for comprehension. A between-subjects design would have addressed the problem of asymmetric transfer. On the other hand, in the within-subjects design, the between-subjects differences were controlled, regarding to differences in individual reading patterns in two reading tasks (reading for comprehension and skim reading).

Another limitation concerning the reading tasks in the experiment was that the two tasks were completely separated. In reality, readers may engage themselves in a highly flexible reading strategy: they may skim read an article until they find an important or otherwise interesting passage in the text, which they then want to read slowly and carefully. After reading an interesting or important passage, the readers may continue skim reading. Therefore, to better simulate the realistic online reading, it would be necessary to allow the participants to switch the task during the trial as often as they want.

Another factor that made the experiment less realistic was that the readers were instructed to first finish reading each article, before clicking a hyperlink and navigating forward in the hypertext space. This was done to receive comparable results with earlier studies of Fitzsimmons et al. (2013, 2014), where the participants simply read articles without a possibility to click and navigate, and they thus read the whole article. However, when readers engage in hypertext reading outside the laboratory, they do not necessary finish reading an article before changing the web page. Instead, they would possibly navigate to another page as soon as they see an interesting hyperlink. This would involve somewhat different eye movements than the current experiment did. In this respect, the nature of the experiment may have been less realistic.

Additionally, in the current experiment, the task was simply to read articles and try to retain some information of the content. This kind of reading and browsing can be rare in real life, as readers usually have an objective for reading, for example that of finding specific information that answers their question. Since reading objectives influence reading behavior, instructing the participants only to read an article which may be meaningless for them, and then measuring how much of the article was retained, is not a very motivating task. Moreover, in a wider learning theory perspective, this kind of reading for comprehension measurement is not very authentic. Current learning theories perceive learning as an active process, where the learner makes synthesis of materials and, as a result, constructs and reconstructs higher-level knowledge structures (eg., Boud & Feletti, 1997; Hakkarainen, Lonka, & Lipponen, 2001). It would be necessary to explore reading comprehension also in a wider perspective with a meaningful objective, and measure higher level comprehension. This is important, especially considering that hypertexts may be most commonly browsed when readers are engaged in higher level learning processes, rather than in learning-by-heart processes.

Finally, the study only explored the reading and navigation behavior in an edited Wikipedia environment (see Figure 2). Although Wikipedia is widely used, and ranked among the ten most popular websites ("Wikipedia.org Traffic Statistics", 2017), the web pages we encounter and navigate daily include a vast number of different pages, varying in their construction, design and appearance. Therefore, the results can not be generalized to all online reading, but it is likely that articles that are similar to Wikipedia design involve similar reading behavior than what was seen in this study.

## 4.3. Future research

It is necessary to further explore reading and navigation on the web, with realistic tasks and web designs. In the future, it is important to investigate hypertext processing in different web environments. Social media networking, for example, is a common internet activity ("How people spend their time online", 2016). Investigating different online tasks, environments, and activities would provide a better picture of the impact that the hyperlinks and the web navigation has on hypertext processing. To study this complex subject, new authentic, yet controlled, online environments need to be build. Currently, generating these experimental environments requires a lot of resources, but if it becomes more accessible, more systematic study of web behavior will be possible.

Although it is important to explore the detailed momentarily cognitive processes in simple reading for comprehension tasks, to find out how hypertexts are used in wider learning processes is also important. If hyperlinks can provide beneficial extra information in a simplified language learning task (Nikolova, 2004), could they also be beneficial in a more complex learning context? In the currently trending socio-constructive theories of learning, such as *flipped mastery model, problem-based learning*, or *progressive inquiry*, learning is perceived as an investigative process of knowledge construction and reconstruction (Bloom, 1984; Boud & Feletti, 1997; Hakkarainen, Lonka, & Lipponen, 2001). These learning theories emphasize the active role of the learner in constructing their individual conceptual networks and higher-level knowledge structures, by making synthesis of materials. Hypothetically, in this construction process expansive hypertext documents could be helpful, as they offer almost limitless access to different sources of information, gatherered in the same place, which saves time from searching individually each piece of information. The unstructured nature of hypertext documents may be demanding for the reader, but on the other hand, it may engage the reader to analyze the content and construct their own conceptual networks. This would be helpful for the overall learning (Cakir, 2008).

The hypertext navigation seems to be a cognitively complex process and there are presumably several factors that contribute to the performance of the reader. The cognitive load related to hypertext navigation, for example, is a factor that should be further explored. The suggested cognitive load in hypertext reading also raises the need to study individual differences in hypertext reading. Cognitive resources, such as working memory capacity, may be crucial for hypertext processing. It is likely that the same hypertext document can be motivating and beneficial for some readers, but overwhelmingly demanding for others. It is important to find out how to make hypertexts accessible and beneficial for all the users. In the ideal web design of the future, the hypertext characteristics would match with the reader characteristics.

## 4.4. Implications

From current and previous studies, it can be concluded that hyperlinked words are not more difficult to process than unlinked words. Although the cognitive processes in hypertext navigation are yet to be explored, web designers can be confident that the visible form of hyperlink is not problematic for reading processes.

However, what words are selected as hyperlinks should be considered in Web design, as readers seem to focus on hyperlinks and may use them as markers of important information (Fitzsimmons et al., 2014). Currently, how the pages are linked is not regularised by any systematic set of conventions, but rather “follows the semantic relationships across pages” (OECD, 2010). It is the author of the document who decides where to add the hyperlinks and how the pages are arranged. Selecting the most important content of the text as hyperlinks optimally helps the reader to gain the most relevant information of the text faster, even when he only has a limited amount of time to go through it.

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