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Expectations and memory in link search

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Abstract

Strategies in searching a link from a web page can rely either on expectations of prototypical locations or on memories of earlier visits to the page. What is the nature of these expectations, how are locations of web objects remembered, and how do the expectations and memories control search? These questions were investigated in an experiment where, in the experimental group, nine experienced users searched links. To obtain information about expectations, users' eye movements were recorded. Memory for locations of web objects was tested immediately afterwards. In the control group, nine matched users had to guess the locations of web objects without seeing the page. Eye-movement data and control group's guesses both indicated a robust expectation of links residing on the left side of the page. Only the location of task-relevant web objects could be recollected, indicating that deep processing is required for memories to become consciously accessible. A comparison between the experimental group and the control group revealed that what was represented in memory was not an individual link's location but the approximate locations of link panels. We argue that practice-related decreases in reaction time were caused by semantic priming. Roles for the different types of memory in link search are discussed.

Keywords: Expectations; Memory; Visual search; World wide web; Human factors engineering

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1. Introduction

The groundbreaking idea in hyperlinking was to embed links directly into text where they could be easily found in their semantic context during reading (Bush, 1945; Engelbart, 1963; Nelson, 1965). Because World Wide Web sites typically consist of a collection of several loosely related documents and services, designers have had to come across additional ways to tie the multiple pages of a site together. Most often, this involves presenting links to internal pages in a panel located on the side of the main content. This static interface is here called *the navigational framework*. A quick glimpse at current web sites shows that navigational frameworks vary considerably from site to site. This inconsistency is problematic, because the user has to deal with each navigational framework individually. In fact, there is evidence that WWW users often get frustrated in trying to search information. Several user satisfaction surveys have indicated that normal users have troubles in finding information in 40–70% of the time from on-line shops (for an overview, see Usability Net, 2003). Even experienced users face problems about 30% of the time. Striking figures like these provide a real challenge for designers and HCI researchers.

One common approach to study information search behavior is to compare different layouts by task completion times or user opinions. An option to this kind of *brute force* approach is to study the mental processes involved in finding information from a page. If designers would understand the psychology of users (Carroll, 1991; Card, Moran, & Newell, 1983; Czerwinski & Larson, 2002; Faulkner, 1998; Olson & Olson, 2003), they could describe, explain, and predict user behavior in novel situations in a way not accounted by the brute force approach. The present study conforms to this strategy, since our purpose is to examine how the human *memory* can either support or fail to support users in web navigation. Our analysis begins from the simple observation that in order to navigate, users need to *select* among many candidate links presented on a page. It is thus critical to understand *how* the incorrect links are avoided and the correct one selected. Previous research in link search has mainly focused on the roles of attention and perception (e.g., Oulasvirta, 2004), whereas the roles of prior knowledge and memory are less well understood (cf. Ehret, 2002).

Our starting point is the widely accepted fact that memory consists of several functionally separate subsystems (e.g., Schacter & Tulving, 1994; Squire, 1992). In this paper we distinguish on one hand between explicit and implicit memories (Graf & Schacter, 1985; Schacter, 1987) and on the other hand between memories and expectations. Even before we see a particular web page, we have *expectations* about the probable locations of links, based on previous experiences with web pages. Users can have *implicit expectations* that are inaccessible to consciousness and consciously accessible, *explicit expectations*. Both types of expectations may have an effect on link search behavior. Whereas expectations are a type of *prior* knowledge or skills, memories are here conceived as representations or skills of the posteriori type: they are about the individual page we have seen. *Implicit memory* (memory without the conscious awareness of the original event that caused it) for a particular page we have seen can help in directing attention to the target more efficiently. In addition, we have implicit *procedural memories* (e.g., Anderson, 1982) of how certain actions (e.g., manual operations with the mouse) have led to a solution of a problem, and these memories can reactivate the correct action sequence upon a revisit to the page. In addition to implicit memories, we can have *explicit, consciously accessible memories* of our experience with the page. Explicit memories can help in finding the target when the automatic processes based on implicit memories or expectations fail. Taken together, a wealth of memories and expectations are involved in different stages of link search, and it would be interesting to distinguish among them. To our knowledge, there are no previous studies that have directly addressed this question in the context of human–computer interaction.

Here it is important to make a distinction between the type of on-line memory that we build during viewing a page and the type of long-term memory of previous visits to a web page. The former type has been investigated earlier in normal reading; It is well known that in reading from a screen or paper, positional information of text is encoded and retained, but only weakly and transiently (e.g., Piolat, Roussey, & Thunin, 1997; Rothkopf, 1971; Therriault & Raney, 2002). Our goal, however, is in understanding the latter kind of memory.

In our paradigm, a participant's task was to find a prespecified link as quickly as possible from a previously unseen page. The idea is that expectations are manifest in search behavior that takes place with previously unseen pages. In order to make interpretations of expectations of link locations, we compared reaction times and eye-movements in three layout conditions: left-, right-, and both-sides navigational framework. We analyzed the number and duration of fixations, their density in different areas, and the direction of first saccade. These data will reveal whether eye-movement patterns differ for different layouts and what is the initial expectation of the link location. The both-sides condition in which the links are distributed equally on the both sides of the page is critical: Directional biases in scanning are an indication of expectations. On the other hand, if eyes dwell equally on both sides, no preference can be assumed, and search is guided more by visual features of the page than pre-existing knowledge. In addition, we analyzed if the patterns of eye movements *change* when the same page is presented more than once. If the patterns change when the page is seen for a second or third time, a memory representation of the page must have been created during the first encounter. If the patterns remain the same across three trials, the search strategies that guide attention are robust, that is, they are not sensitive to features of individual pages. In that case, we can conclude that expectations guide search, not memories of individual pages.

After the completion of search, a test for location memory was administered. Without seeing the page, the participant had to indicate where he or she thought a shown object was located on the page. The test items were either links or content objects captured from the page. Because web objects can be correctly located without seeing the page, based on prior knowledge on the prototypical locations of web objects (e.g., logos are usually on the top left corner), we compared the localization accuracy of the experimental group to a group that had to give educated guesses on the locations of the same objects without seeing the page. By subtracting the contribution of guessing from the localization accuracy of the experimental group, we could estimate how well the locations of task-irrelevant (content area) versus task-relevant (navigational framework) objects are actually remembered (versus guessed). Furthermore, analysis of the control group's guesses will give us an idea of what the users' consciously introspectable, or explicit, expectations on link locations are. Explicit expectations may well differ from implicit expectations, a pattern repeatedly demonstrated in the studies of implicit learning (e.g., Reber, 1976). We also examined if practice has a different effect on memory test performance than on eye-movement patterns. This would implicate that representations used in the memory test versus in the control of attention are separate. This finding would raise the question of the roles of these different representations. If both measures respond similarly, it would imply that it is probable that the same underlying representations control responses in both measures.

2. Method

2.1. Participants

Nine experienced web users (one female, eight males) volunteered for the *experimental group*. All participants used the WWW daily (at least for one hour per day) in their work, had at least college education, and five or more years of daily experience with graphical browsers. They were naïve to the purpose of the experiment. All participants had normal or corrected-to-normal vision. Nine other experienced web users, matched in age and years of web-related experience to the experimental group, volunteered for *the control group*.

2.2. Materials

The materials consisted of 15 web pages with financial, political, or educational content. In order to make sure that the participants, who were all from Finland, would have no prior experience with the pages, they were selected from the domains of Australia and New Zealand. The content area of all materials always included text, a maximum of two graphical elements, and one to three headers (in bold typeface or in bigger font size than main text). All link panels were arranged vertically and all links conformed to the underlining convention.

Three layouts of each page were created using graphics software: link panels located on the left, on the right, or on both sides of the page. The both-sides layout was constructed from the one-column format by moving half of the links from the bottom of a panel to the other side. Here, both columns looked visually identical except for the link texts. Fig. 1 illustrates the three layouts.

2.3. Procedure

Participants were told that the purpose of the experiment was to study the effects of web page design on reaction times and eye movements. In order to make sure that

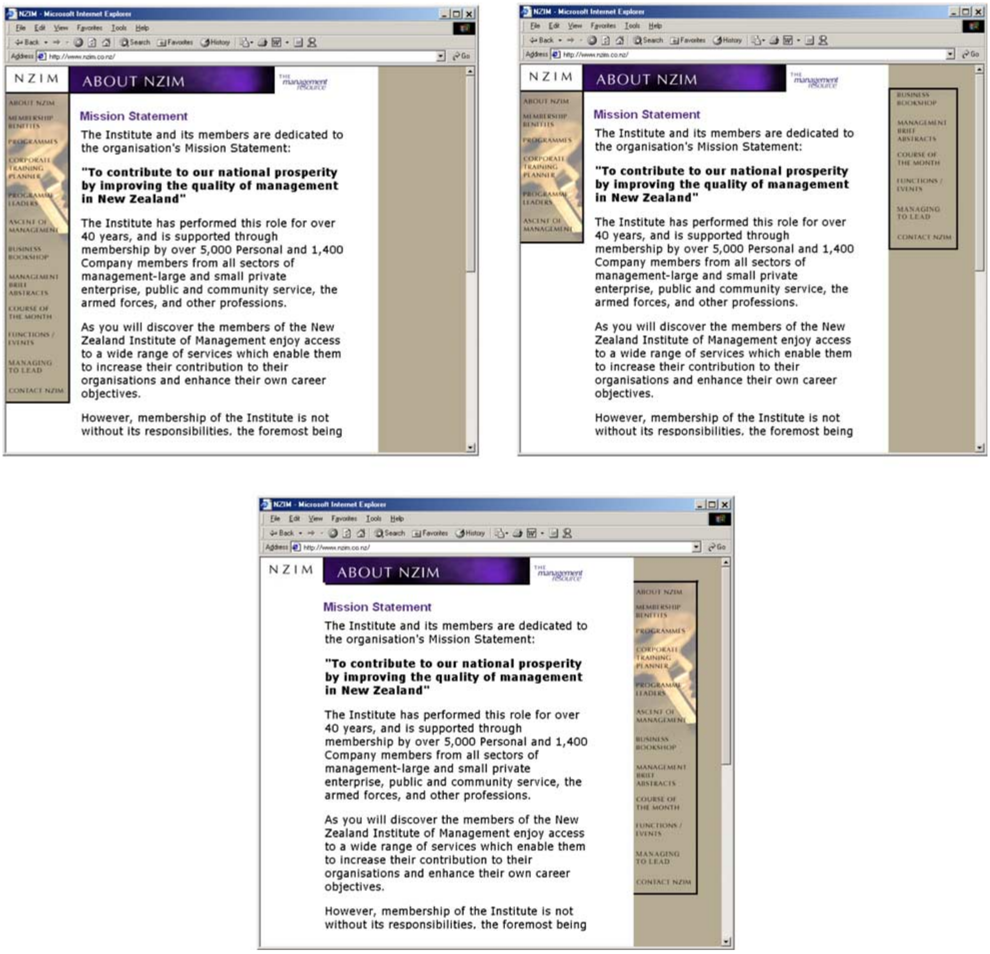

Fig. 1. Left-side (left), both-sides (center), and right-side (center) layouts.

the participant understood and complied with the instructions, two or three practice trials were completed before starting the experiment. Participants were run individually.

In both groups, the *description of the target link* was shown in a black 32 pt font on white background at the center of the display for 3000 ms. The link description was given in Finnish (e.g., ''Kotisivu''), while all links were in English (e.g., ''Home page''). Hence, the participants knew a description of the target but did not exactly know what it was called in the user interface (see Paap & Cooke, 1997). The description was presented at the center of the screen to guarantee that participants fixated at the center of the page when the web page appeared. In the experimental group, the description disappeared and the web page appeared after the 3000 ms. Participant's task was then to find the target link as quickly as possible and simply press the left mouse button. Because the time to acquire a target with a mouse would vary according to its distance and size (in accord with the Fitts' law), and because controlling mouse movements would themselves require eye-movements and could thus hinder interpreting the "true" search patterns, we only required participants to press the button when they had found the link. However, in order to control that the correct link was really found, the page disappeared immediately after the button was pressed, the mouse cursor reappeared, and the subject had to indicate the location of the target on a blank browser window by pointing it with the mouse and pressing a button. In the control group, participants were not shown the web page but a blank screen with a text asking to press mouse button as quickly as possible.

After completing the search task, memory for locations of two web objects was tested. A navigation object (a non-target link) or a content object (e.g., a header, table, text, or graphical element) was presented as the mouse cursor and the task was to indicate its location with the mouse and press the left mouse button. All test items were separable web objects (i.e., they were complete and did not contain parts of other objects), rectangular in shape, and selected randomly from the page (as judged by the experimenter). Participants were instructed to make their best guess if they did not exactly remember the location, and to be consistent when coming across the same page again. If the participants had any memory for the visuo-spatial configuration of the page, some cues (e.g., background color) of the test item could be used to infer the location of the item. If, by contrast, they had no idea on the location of the test item, their level of accuracy would be on the same level with the control group. On each trial, memory for one content and one navigation object was tested.

For each participant, all 15 web pages were presented three times, every time with a novel target and novel memory test item. In other words, each target and memory item was presented only once for each participant. Any two repetitions of a page were separated by 14 other pages in the sequence. Totally, there were (three repetitions for 15 pages) 45 experimental trials per participant. Participants were instructed to perform as accurately and quickly as possible on all trials. To encourage concentration on searching the target as quickly as possible, instead of memorizing the page layout, continuous feedback on the performance was provided by showing reaction times on the screen after each trial. Participants had an opportunity to take a short break between trials.

2.4. Design

Presentation orders of targets, web pages, and layout were counterbalanced across participants by creating nine presentation sets. Layout, number of page exposures, and type of memory test item were controlled within subjects. Reliance on memory (experimental group) versus expectations (control group) was controlled between subjects.

2.5. Apparatus

The stimuli were displayed on a Philips 170B 17 in. LCD flatpanel monitor with a Dell Dimension 4100 computer. Display resolution was 1024×768 pixels. A chin rest was used to stabilize a participant's head. Similar equipment (17 in. flat screen CRT monitor and a Dell Latitude computer) was arranged for the control group, with the exception that no chin rest was used.

For the experimental group, eye-movements were recorded using a head-mounted gaze tracking system (SMI iView). A participant's right eye was monitored with a miniature infra-red camera while one infra-red LED illuminated the eye. The eye tracking system was controlled by a PC computer. It identifies the centres of the pupil and corneal reflection, from which it can compute the point of regard.

Video images of the pupil and corneal reflections were captured at 50 Hz by the eye tracker. The resolution of the system is better than one degree. The eye movement system was calibrated using a set of 9 screen locations. iView-software was used to detect fixations and calculate their durations. To be considered a fixation, a gaze point had to fall within a spatial area between about 30×30 pt, and had a minimum duration of 80 ms. Gaze position in iView is related to the calibration area settings. In the present study, this area was 720×280 pt.

3. Results

The following analyses are performed at the significance level of 0.05. All reports, unless otherwise mentioned, are from the data of the experimental group.

3.1. Reaction times

A 3 (*Layout*) $\times$ 3 (number of trials with the page, *Trials*) repeated measures analysis of variance (RM-ANOVA) was conducted for reaction time data. The main effect of Layout was not significant, $F(2,16) = 0.5$, *n.s.*, but the effect of Trials was, $F(2,16) = 3.9$. A planned test for the decreasing monotonic trend (coefficient set [1,0,−1]) was significant, $F(1,8) = 9.2$, indicating that participants could find the target faster with more trials. The interaction between Layout and Trials was not significant, $F(4,32) = 1.0$, n.s.

3.2. Eye movement data

Due to problems in data collection, the results of only six participants were analyzed. A two-way RM-ANOVA was performed on the number of fixations and fixation durations. Data on these two variables are presented in Table 1. Surprisingly, the main effect of Trials and Layout, and their interaction, were not significant on the number of fixations, all ps > 0.1. For fixation duration, however, the effect of Layout was significant, $F(2,10) = 4.1$, but the effects of Trials and the interaction between Trials and Layout were not, both ps > 0.1. Simple contrasts suggest that fixation durations were shorter when all links were on the left-hand side of a page than when they were distributed on both sides.

We counted the number of gazes to the following *areas* of a page: link panels (left/right), content area, headline (above content area) and outside the page. A two-way

Table 1
Average fixation duration (in milliseconds) and average fixation number per trial as a function of Layout and Trial

	Panel on left			Panel on right			Panel on both sides		
	1. Trial	2. Trial	3. Trial	1. Trial	2. Trial	3. Trial	1. Trial	2. Trial	3. Trial
Fixation duration (ms)	238	221	233	251	240	272	257	240	226
Fixation number	15	12	11	13	11	12	11	12	10

RM-ANOVA (Area, Layout) showed that the effect of Area was highly significant, $F(4, 16) = 25.4$, as was the interaction between Area and the Layout, $F(8, 32) = 4.5$. Observers fixated more often on the left side when the link panel was on the left and on the right side when the panel was on the right. More interestingly, they gazed more often on the left side than on the right side when the links were distributed.

We also analyzed the direction of the first saccade. Most of the first saccades (93%) were directed to the link panels. A two-way RM-ANOVA (Fixated Area, Layout) showed that the effect of Fixated Area, $F(4, 16) = 51.0$, and the interaction between Fixated Area and Layout were significant, $F(8, 32) = 6.1$. Observers typically fixated first on the left side of the page. More interestingly, they fixated more often first on the left side than on the right side even when the links were distributed (in the both-sides condition).

3.3. Memory for locations of web objects

Accuracy of location memory was analyzed in two separate RM-ANOVAs, one for navigation and another for content objects. For content objects, which were never target items, no significant effects were found, all Fs < 1.0. Overall level of memory was very poor. In fact, it was at the same level with the control group who had never seen the web page and had thus to guess the locations. An independent groups t test was not significant, $t(16) = 0.8$, confirming that the groups performed at the same level.

For navigation objects, there was a significant effect of Layout, $F(2, 16) = 6.6$. Memory for link location was worse for the two-sides layout than for the one-side layouts. Simple contrasts showed significant differences between the two one-side layout and the two-sides layout, both Fs > 6.7, but a non-significant difference between the two one-side-only layouts, $F(1, 8) = 0.9$. The main effect of Trials and the interaction between Layout and Trials were both non-significant, both Fs < 0.9, indicating that practice with the page did not help to overcome this uncertainty.

In contrast to content objects, locations of navigation objects were significantly (38%) more accurately remembered in the experimental group than in the control group, $t(16) = 3.9$. However, the experimental group performed almost as poorly as the control group both with left-side and both-sides layouts, but not with right-side layouts. There was a strong tendency in the control group to guess that test items

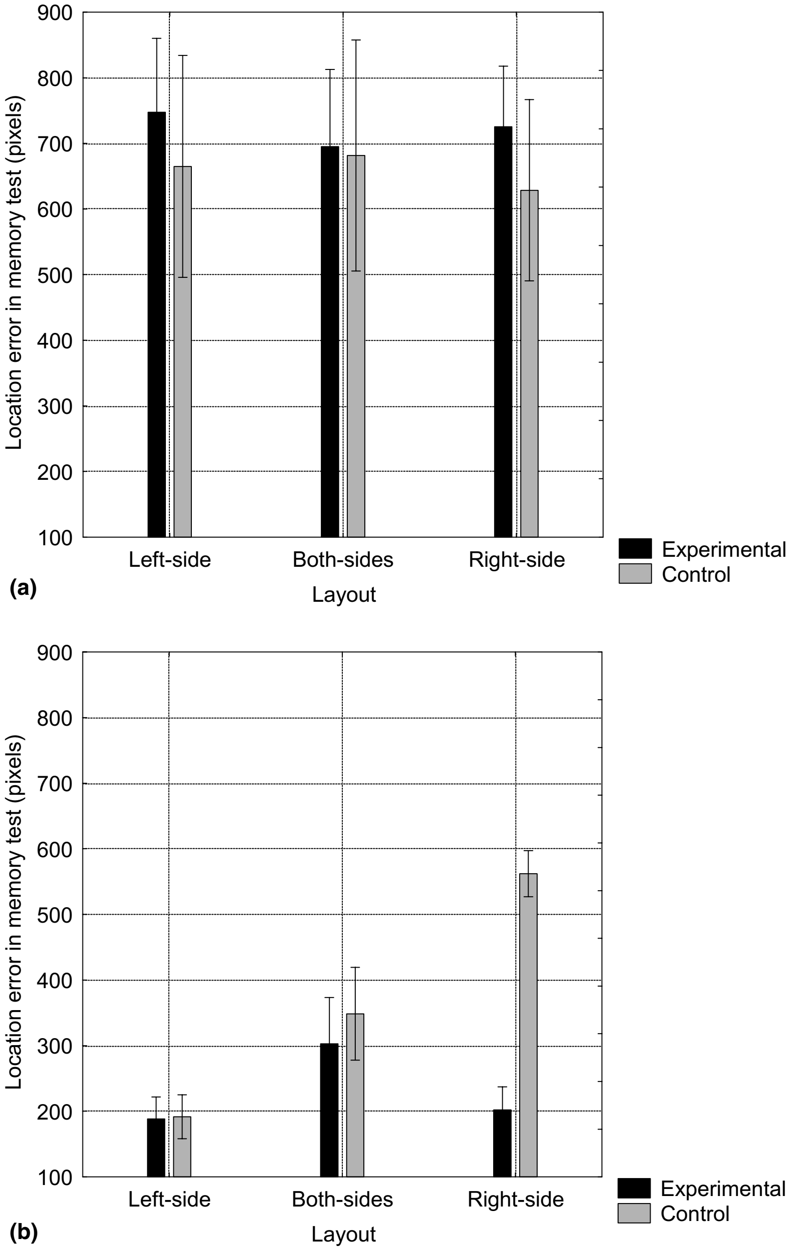

Fig. 2. Location errors (in pixels) for objects in memory test in experimental and control groups. (a) Content objects. The experimental group was at the level of the control group who could only guess the locations. (b) The experimental group performed almost as poorly as the control group in the left-side and both-sides layouts, but not in the right-side layouts. (Vertical bars denote 95% confidence intervals for the means.)

were on the left side of the page. This pattern reveals that the experimental group remembered only the location of the whole link panel, not the location of an individual non-target link. Had they remembered locations of individual links, they should also have outperformed the control group in the left- and both-sides layouts. However, they only outperformed the control group in the right-side layout. In this case, they benefited from knowing the side of the panel. Fig. 2 presents this relationship and between groups comparisons (with 95% confidence intervals).

We then investigated if the distance of a test item to the target was related to the accuracy of location memory. That is, if an item on a web page is located near the to-be-found target, is it more accurately remembered? For this purpose, we calculated the correlation between the mean error of location judgments and the distance of test item to the link target. For content objects, this correlation was weak, $r = 0.02$, and non-significant, whereas for navigation objects, the correlation was strong and highly significant, $r = 0.5$, $p < 0.001$.

4. Discussion

Our starting point was the fact that memory is not a unitary system but consists of various components, each of which has a unique function in link search. Implicit expectations guide attention irrespective of conscious awareness. Explicit expectations are consciously accessible beliefs of locations of links, and implicit memory represents previous visits to a particular page in a form that is inaccessible to conscious awareness, whereas explicit memory consists of episodic accounts of previous visits in a form accessible to visual and verbal consciousness. In the following, we re-examine the results in terms of what they reveal us about expectations and memory and propose how they may contribute to link search.

4.1. Left-preference in expectations

Our results present evidence for strong *left-preference*: experienced web users expect links to locate on the left side of the web page. Fixations were shorter when all links were on the left side rather than on both sides, and more visits were made to the left side of the page in the both-sides layout condition. What is perhaps more important is that first saccades were most often directed to the left side of the page. Also participants in the control group, when asked to guess where a web object would be located, were inclined to organize links into a vertical column to the left side of the page.

An important contribution of this study is that we show, in one experimental setup, the *pervasive nature of left-preference*. It extends to measures of both implicit (eye-movements) and explicit (guesses in the control group) expectations. Whereas no previous studies on implicit expectations were found, explicit left-preference agrees with Bernard (2001). In his study, participants placed cards representing common web objects to a 8×7 grid to where they expected them to be located on a typical web page. Internal links were expected to locate on the left side and external links were expected to locate on the left and right side. The procedure in Bernard's study was, however different from ours: He asked participants to think about the most common location for any instance of a specific web object. Answering to this question requires a higher-level inference in the absence of concrete stimuli, whereas we presented our participants with real links and asked them to guess where they would be in a particular page. It was by no means self-evident that measures of implicit and explicit expectations both showed left-preference. Patterns learned implicitly can differ radically from those learned explicitly, and wrong rules learned explicitly can interfere implicit learning (Reber, 1976). Dissociations between conscious and unconscious beliefs are common in other domains of human cognition as well (Kihlstrom, 2002).

The fact that implicit and explicit expectations converge can maybe best explained in ecological terms, if one assumes that left-preference reflects a true tendency of links being on the left. Although no systematic studies pertaining to this assumption exists, a short look at a sample of web pages convinced the authors that this might be the case: links are usually arranged in a vertical column that resides on the left side of the page. Implicit learning, the process that is responsible for the extraction of general tendencies, is considered to work as a kind of coincidence detector (Reber, 1993), a mechanism that in this case allows the person to reinforce the tendency to look at the left side of the page because links are located there more often. Through daily experience with web pages, experienced users have become consciously aware of the tendency of links residing on the left side, and they are able to use this knowledge strategically in making decisions. With less experienced participants the pattern could change, explicit and implicit expectations might not converge. The ecological explanation highlights the fact that left-preference is a rational way of optimizing search behavior: If links are typically located on the left side of the page, it makes sense to make a quick look to the left side in the very beginning of the search, because most of the time this strategy will be successful. A more demanding and slower strategy would be to decide the scanpath on-the-fly according to the particular features of the page. An underlying assumption behind this explanation is that subjects behave rationally, that is, they seek maximum gain with minimal costs (Anderson, 1990). When the environment is structured, people learn to exploit the structure to coordinate their behavior in a coherent manner.

Basing on the discussion above, the role of expectations in navigation is clear-cut: When a page is visited for the first time, expectations guide attention to locations that most probably contain the target. The role of expectations is therefore to make a first guess on the potential location of the target. If left-preference is a general tendency among web users, it backs up the common design guideline according to which links should be positioned to left and important links should be positioned higher in a list than less important ones (e.g., Research-Based Web Guidelines, 2003). Links organized in this fashion can be found more *reliably*, because their location is expected, but not necessarily *faster* as our reaction time data would indicate. If the locations of links do *not* conform to expectations (as in the condition where all links were on the right side of the page), one could hypothesize that this would lead to less reliable search performance. On the other hand, since the page would be scrutinized longer in this case, the perceptual representation would be more complete, and thus, the page would be better remembered. In other words, the question is that if left side was preferred in implicit and explicit expectations, why did this not help the participants in finding the target quicker when the expectation was correct (i.e., the link actually was on the left side)? Instead, reaction times in the search task were at the same level across the three layout conditions, a result that supports Bernard, Hull, and Drake (2001) findings. They found no differences between link layouts in search accuracy, time, or efficiency, notwithstanding the fact that embedded links were subjectively preferred over other layouts.

Despite the finding that participants considered the left side as the most probable location for links, their subjective predilections may differ from these. Bernard et al. (2001) found that although there were no differences between different link layouts as regarding task efficiency, participants nevertheless subjectively regarded embedded linking as easier to navigate and more easily comprehensible and associable to key information than other design solutions. Interpreted together with the findings from the present study, these results leave designers with a difficult question: should one adhere to left-preference and place links to the left side of the page where users expect them to be located and where they first look at, or should one prefer embedded linking because it is subjectively considered more usable by the users? In some cases, a good designer may consider both.

4.2. Robustness of expectations

Implicit expectations make it possible to direct attention quickly to the target. Left-preference is thus a rational strategy, given the real-world tendency of links being on the left side. However, supposing that a page has its links on the right side, it would make sense to look straight to the right side of the page. The question, then, is how many trials are needed for the expectations to change? From the results of this experiment, some cautious answers can be given.

Since there was no evidence that search patterns change with practice, expectations seem quite *robust*. They are not (quickly) updated for every individual page that does not conform to the expectation. Had a mental representation of the link locations been built, we should have observed an effect of Trials on any of these variables. Our data suggest, however, that after three trials expectations concerning typical link locations, control link search.

The participants, however, saw the page only three times. If finding a target took, say, 3 s on average, the participant had seen the page for a total of only 9 s before the onset of the last memory test. It is likely that with more practice the search patterns would change. However, the proportion of pages that are visited more often than three times is actually quite small (Tauscher & Greenberg, 1997). Therefore, we studied here an ecologically valid case.

Other research, however, suggests that after more trials such learning can occur. For example, in their contextual cuing paradigm, Chun and Jiang (1998) showed that at least after five trials with a page, search patterns change in accord with information gained during the very first fixations. It is likely that expectations are resistant to a quick change, because the gains from adapting them individually would be small. Most of the time in link search is spent on decision-making upon whether a link candidate matches the goal description.

4.3. Encoding of web object locations requires deep attentional processing

Our data revealed an interesting single dissociation in memory for locations of web objects: participants who saw the page remembered locations of content objects at a chance level (i.e., at the level of the control group who did not see the page but gave educated guesses of the locations), but remembered locations of navigation objects substantively (38%) better than chance. Given that the participants had at least fixated on the content area, how can it be possible that practically nothing was remembered? Because content areas were looked at, although admittedly only shortly, it is clearly the case that not all objects that are looked at are remembered.

Our explanation stems from *the principle of levels of processing* (Craik & Lockhart, 1972), according to which durable memory is always a corollary of the operations carried out during encoding. In this case, different web objects are processed differently during search and thus acquire different statuses in memory. *Deep, elaborative processing* of a stimulus yields durable memory traces that stay accessible for a long time, whereas shallow surface-feature oriented processing yields traces that decay quickly. In our experimental task, participants were required to find a link that was never located within the content area. Thus, participants could ignore the area based on its location and surface-features and direct attention to areas that more likely contained links. In fact, task-irrelevant objects can be ignored very effectively, so effectively that large changes in their appearance are not consciously perceived (Mack & Rock, 1998; Rensink, O'Regan, & Clark, 1997). The type of processing content objects received was thus shallow. In contrast, processing of navigation objects required that they were compared to the description of the target residing in working memory. This kind of semantic processing is much closer to deep processing that produces durable memories. Deep processing of a web object is, from this point of view, sufficient for a consequent memory for its location.

The strong correlation between a navigation object's distance to the target and memory error can be explained in a similar way. The closer an item is to the target, the more probably it has been processed during the search. Specifically, we can assume that links are processed from top to bottom (e.g., Aaltonen, Hyrskykari, & Räihä, 1998), which makes the probability of being processed deeply higher for those objects residing in the same panel above the target. In contrast to navigation objects, the correlation for content object's distance and memory error was very weak. Although the content objects are scanned initially at least to some extent, content objects are not selected for further processing, and are therefore not subsequently recollected.

4.4. Only locations of groups of links are encoded

There is some evidence that participants only remembered locations of the panels, but not of individual links. When all links were on the left side, the experimental group performed at the level of the control group, that is, the experimental group did not get any advantage of actually seeing where the links were. The experimental group performed better than the control group only when the links were on the right side. Apparently, the experimental group only remembered on which side the links were located and did not remember the exact location of individual links.

One limitation of the study is that memory for a *target* was not tested in later trials. We thus do not know whether targets have a special role in memory. It is possible that target links are better remembered, because targets represent successful actions that bring the person closer to the goal, whereas rejected items have no role in goal-pursuit. Indeed, Oulasvirta (2004) found that locations and surface-features of target links were more accurately remembered than non-targets. Together these results suggest that locations of rejected non-targets are not encoded, whereas locations of target items are.

4.5. Savings in reprocessing objects

In addition to expectations and explicit memory for locations, the data may manifest a third type of memory: savings in reprocessing of objects, a form of implicit memory known as *priming* (e.g., Meyer & Schvaneveldt, 1971). In particular, we observed that although search strategies did not change over the course of the experiment, target links were found faster. If the improvement reflected more efficient search strategies due to learning of locations, also the number of fixations should have decreased, and the links panels should have been immediately attended to. However, the strategies seemed to remain the same over the three trials. Or, if the reaction time reflected explicit instead of implicit memory for locations of objects, we should have observed enhanced performance in the memory test as well. Instead of the perceptual-attentional stage of search (e.g., the programming of eye-movements or the analysis of visual features of the page), the decrease is therefore likely to manifest savings in processing that take place at the cognitive stage of response selection and generation.

According to our tentative explanation, the decrease in reaction time was caused by unconscious activation of object's representation in the semantic long-term memory (semantic priming; Mandler, 1980). When an object is encountered, its representation is activated or primed in long-term memory. If this activation still remains when the object is processed at another time, reprocessing is faster than the initial processing, thus the term "saving" (Ebbinghaus, 1885/1913). An important limitation to this kind of implicit memory is that it can only occur to items that are already represented in memory; novel meanings or conjunctions of features cannot benefit from priming (Mandler, 1980). The speed-up caused by priming would explain why reaction times decreased in the absence of practice-related changes in eye-movements or memory. The hypothesis deserves a more rigorous examination, however.

Because finding a link panel is a relatively easy task due to the availability of several distinctive perceptual cues (links are usually blue, underlined, and organized in a vertical column), the most time-consuming task is to find a particular link among a group of possible targets. When primed links are processed again during revisits to the page, processing can proceed faster. Thus, the role of priming is to make this time-consuming process a bit faster. If this hypothesis is true, designers should put more effort in reducing the amount of time spent in processing a link by using short, conventional, and simple expressions (that have strong and easily activated correspondents in semantic memory).

4.6. Expectations versus memory

An apparent controversy remains, however: Supposing that the participants could explicitly recollect the locations of link panels only after one trial, why did they not look straight at the link panel? The probable explanation is that the task of searching a link is too easy for expert users to be performed on the basis of consciously recollected memory (Melcher & Kowler, 2001), because recollection of the location of an object is slow and requires mental effort. Mental effort would be required both for searching the memory and translating the search results into responses, operations that take time in the order of seconds. In contrast, expectations can be recruited faster and with less effort in the order of tenths or even hundreds of seconds. Lauwereyns and d'Ydewalle (1996) made an analogous conclusion from their study of expert's eye-movements and verbal protocols.

Has explicit memory for locations, then, any role in link search? Instead of the online control of eye-movements, explicit memory may be called for in two cases: (1) when there is a need to remember information about the web page which is not itself visible, or (2) when the automatic processes fail and users must relapse into voluntary control of action. The first case may occur, for example, when planning information retrieval strategies or verbalizing information about a web site to other people. The second case may occur, for example, if the user fails to find a target or makes an error and notices that. Many times when the link is not found only by relying on implicit expectations, explicit expectations or memories are called for. This highlights the need for placing important links to expectable locations. In both cases, voluntary control is needed in considering alternative strategies in approaching the problem. This kind of decision-making obviously draws on consciously recollected memories on how information is organized in the user interface.

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