The Role of Mouse Movements in Interactive Search

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Abstract

This paper describes two experiments that aimed to investigate the relationship between mouse movements and eye movements in an interactive task. In Exp 1, participants were free to move the mouse whilst performing a single-page web menu search task. The results show that eye movements depended on the quality of the distracter items present in the menu. Similarly, the frequency of mouse movement patterns changed according to the quality of the distracters that surrounded the target. When more distracters competed with the target for selection, participants' used the mouse to "tag" potential targets whilst their eyes were free to scan the rest of the menu. In Exp 2, mouse movements were restrained. Results show that when people were not allowed to move the mouse, choice accuracy and search time decreased and eye-movement patterns became independent of the quality of the distracters present in the menus. The results are discussed within a rational analysis framework (Anderson, 1990) and compared to existing models of interactive search.

Keywords: Human-Computer Interaction; Rational Analysis

Introduction

Research has shown that when searching for information in a web-based menu people do not always scan every item (e.g. Pierce, Parkinson & Sisson 1992; Brumby and Howes, 2003, 2004). Furthermore, this behaviour has been attributed to the pattern of relevance of the items in the menu with regards to a pre-specified task goal. Interactive search on the World Wide Web involves searching for information whilst interacting with an interface, usually in the form of the manual selection of links using the mouse. The mouse cursor is a visual object which has the potential to interfere or assist with visual search.

Few investigations of interactive search have tried to understand whether people make use of the mouse to assist their task. Byrne et al (1999) investigated mouse movements in the use of click-down menus. They identified at least two strategies employed by participants: a single move once the target item had been located by visual search, and the many-move strategy that trails the eye-movements. Further evidence that the mouse is used to aid interactive search was found by Mueller and Lockerd (2001), in a study that identified correlations between eye and mouse movements. They report the same two strategies of mouse use as Byrne et al. Similarly, Chen et al (2001) have argued that gaze position and mouse cursor position are correlated. In summary, eye and mouse movements appear to be linked.

While there appears to be converging evidence that people use the mouse in particular ways during interactive search tasks, its role is often overlooked.

In this paper, we report the results of two experiments designed to test whether using the mouse is important to search efficiency. We hypothesise that mouse pointing is likely to aid interactive search by enabling the user to visually "tag" certain parts of the display while the eyes are free to move elsewhere and access the "knowledge in the world". In order to develop a comprehensive understanding of interactive search, mouse behaviour patterns should not be overlooked.

In Experiment 1, participants were able to make free use of the mouse whilst performing interactive search tasks on single level menus. Several eye-movement metrics were analysed in order to characterise eye-movement behaviour when the relevance of the items contained in the menus was manipulated. The number of items skipped (items that are not fixated) is likely to depend on the cost and the expected gain of scanning all items in the menu when compared with the cost and gain of selecting an item. According to Brumby and Howes (2003, 2004), searches can be self-terminating (when a target is selected as soon as it is viewed) or redundant (when more items are scanned after the target has been viewed). In light of this, the number of post-target visits was taken as a measure of how sure people are when they make a link selection. In addition, mouse-movement patterns were identified so they could be related to eye-movement behaviour. Accuracy and inspection time were also measured since they are likely to depend on the quality of the distracter items that surround the target. Experiment 2 replicated the first experiment with new participants who were restrained from using the mouse during search. By comparing their performance and eye-movement behaviour to those of the participants in Experiment 1, we hoped to identify the benefit that particular mouse-movement strategies have on task performance. If mouse pointing is used to assist search, one would expect that when participants cannot move the mouse, searches are likely to be longer and more redundant. This is even more likely in the conditions where more distracters are compete with the target, than on the "easier" conditions (where all distracters are irrelevant).

Experiment 1

Method

Participants. Ten adults, seven male and three female (mean age of 26.3 years) from the University College London Interaction Centre volunteered to participate in the experiment. All participants reported normal or corrected-to-normal vision and all had more than 5 years of computer experience, specifically on internet searching.

Procedure. At the beginning of each trial a goal task was presented at the top left of the screen. After reading the goal task at their own pace, participants had to click with the mouse for the corresponding menu to appear, at which point the goal task disappeared.

In the instructions presented prior to the start of the experiment, participants were told to start scanning the menus from the top item and search downwards. When they found an item that they thought would most likely lead to the completion of the task, they should select it by clicking on the item. Participants were also informed that they had to perform the task as quickly as possible but their choice was important. Participants' eye movements were recorded throughout. Mouse patterns were recorded by the experimenter by analysis of AVI files generated by the eye-tracker software. Mouse "fixations" were pauses over a link that lasted for a minimum of 100 ms.

Stimuli and Materials. Stimuli consisted in single-page menus built from pre-tested menus, generously provided by Brumby and Howes (2003). The original menus were developed using real Web examples and contained 16 to 20 items, rated on a 5-point scale in terms of relevance to a specified task goal (e.g. "check your bank balance"), where 1 – item is very relevant to the task goal (high information scent), and 5 – item is totally irrelevant to the task goal (low information scent). According to their median ratings and for the purpose of menu construction items were divided into the following categories: 1 – target, 2 – good distracter, 3 – moderate distracter, 4 – bad distracter and 5 – very bad distracter. The better the distracter, the higher the information scent it carried, i.e. the more it competed with the target for selection. Brumby and Howes's (2003) menus were reduced to 10 items each and allocated to one of four types: A, B, C and D. Menus type A only contained very bad (low scent) distracters (median rating of 5) and one target (median rating of 1). Menus type B contained one target, 4 bad distracters and 5 very bad distracters. Menus type C contained one target, 3 moderate distracters, 3 bad distracters and 3 very bad distracters. Finally, menus type D contained one target, 2 good distracters, 2 moderate distracters, 2 bad distracters and 3 very bad distracters. In summary, overall scent value of the distracter items increased from menus type A to menus type D. The experimental session included four of each menu type, totalling 16 trials, and participants only saw each menu once.

Targets either appeared in positions 3 or 8 (on a 50/50 ratio) and the relative distribution of the distracters was also manipulated. In half of the trials, distracters were presented in blocks and in the other half they were interspersed. Examples of menus are presented in Table 1.

Four filler trials (one every four valid trials) were included to reduce the predictability of target position. The menus for these trials were also part of the original Brumby and Howes (2003) menus, but the target appeared in four random positions and never in positions 3 or 8. The distracters' relevance and relative distribution were not manipulated. In total, each participant carried out 20 trials.

Table 1: *Examples of four different menu scent patterns used in the experiment. Numbers represent median relevance ratings with relation to a specified task goal. The target was always rated 1 (high information scent) and appeared in either position 3 or 8, and distracters varied in their quality and relative distribution (blocked or interspersed).*

Menu type			
A	B	C	D
Target in position 3	Target in 8	Target in 3	Target in 8
	Blocked distracters	Interspersed distracters	Blocked distracters
5	4	3	2
5	4	4	2
1	4	**1**	3
5	4	5	3
5	5	3	4
5	5	4	4
5	5	5	5
5	**1**	3	**1**
5	5	4	5
5	5	5	5

Menus were positioned at a distance of 2.5 cm (2.4^o visual angle) from the left edge of the screen and 3.5 cm (3.3^o visual angle) from the top edge. Items were presented in blue colour and font *Verdana*, size 12. The distance between each menu item was 0.65 cm, which subtended 0.6^o of visual angle. Menus were presented at a resolution of 1280 by 1024 pixels (16 bit colour) on a 17" TFT *Tobii* monitor. From the 60 cm distance (optimal distance required by the eye-tracker for accurate data collection), the screen subtended horizontal and vertical viewing angles of 25.6^o and 29.2^o of visual angle, respectively. The experiment was run by *Visual Basic 6.0* which also collected data from the forced-choice discrimination task. Eye movements were recorded using a *Tobii* 1750 eye-tracker and data was collected by *ClearView 2.4.1*.

Results

Target selection and search time. In most cases, participants selected the target item (scent 1). However, that did not happen on 7.7% of trials. Of those 7.7% of trials, choices involving an item other than the target (scent 1) occurred in 54.5% of menus type D, 36.4% of menus C and 9.1% of menus B. Most of the alternative choices were items rated scent 2 (36.4%) and 3 (54.5%). Only one alternative choice was an item rated scent 4. Overall, participants were very accurate choosing the correct target in 92.3% of the trials.

The effect of menu type, target position was analysed via a 4 (menu type) x 2 (target position) analysis of variance (ANOVA). Total search time until target selection was

found to depend on the type of menu ($F_{(3,27)} = 18.019$, $p < .001$), where search time increased as the number of relevant (high scent) distracters increased. Participants also took more time to select the target when it was positioned later in the menu, averaging 6362 ms when the target was in position 8 and 5017 ms when it was in position 3 ($F_{(1,9)} = 29.450$, $p < .001$); see Figure 1).
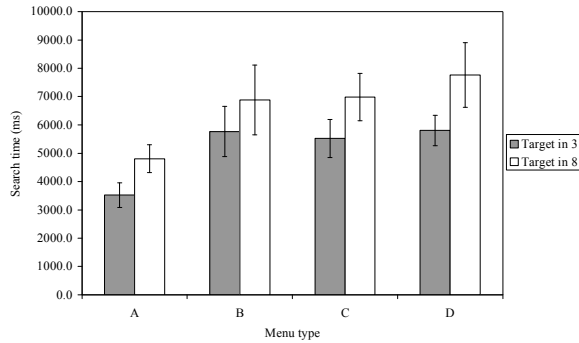
Figure 1: *Total search time according to the type of menu, averaged across participants, as a function of type of menu, where the relevance of the distracters presented together with the target increases from A to D; and target position within the menu (3 or 8). Error bars represent ± SE.*

Number of items skipped. More items were skipped (not fixated) when more irrelevant (low scent) distracters were present in the menus ($F_{(3,27)} = 15.595$, $p < .001$) and when the target item was positioned earlier in the menu ($F_{(1,9)} = 112.675$, $p < .001$). These results are illustrated in Figure 2. There was no effect of the way distracters were distributed on the number of items skipped.
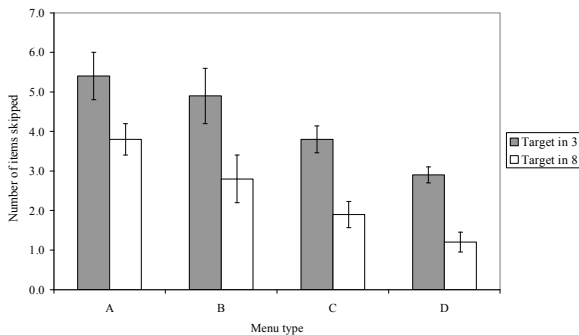
Figure 2: *Number of items skipped with each type of menu, averaged across participants; and according to the position of the target item within the menu. Error bars represent ± SE.*

Post-target visits. When menus contained more relevant distracters, more visits were made to other items in the menu after the target was assessed (redundant search) than when the menus contained more irrelevant distracters ($F_{(3,27)} = 9.511$, $p < .001$). In addition redundant searches were also more typical when the target was placed earlier in

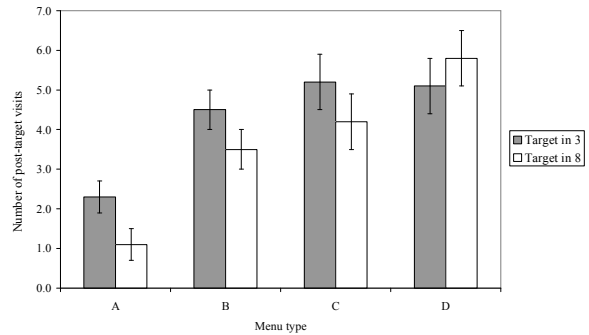the menu ($F_{(1,9)} = 5.123$, $p < .05$). No interactions were found. Results are illustrated in Figure 3.

Figure 3: *Number of post-target visits, averaged across participants, as a function of menu type and target position. Error bars represent ± SE.*

Although the majority of scan paths obtained exhibited an idiosyncratic shape, results from the eye-movement data indicate that when menus contained more relevant distracters, searches were longer, more visits to all items were made overall, more items were skipped and more visits were made to the target prior to selection. These measures can be related to self-terminating behaviour and redundant searches (see Figure 4).
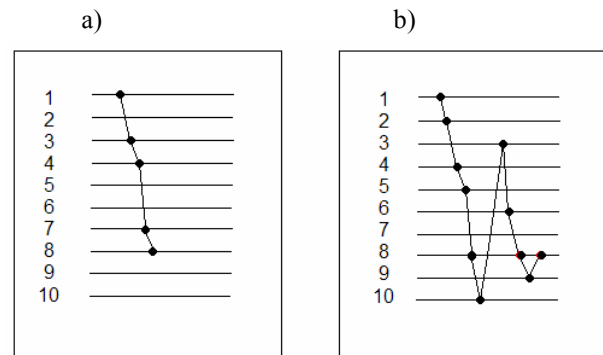
a)   b)

Figure 4: *Eye-movement scan with target in position 8 in a) menu A for participant 4; and b) menu D. In a) scanning was shorter, more items were skipped and the target received only one fixation (self-terminating search). In b) search took longer, almost all items were fixated, the target received multiple fixations before being selected and other items were fixated after the target was visited (redundant search).*

Mouse movements. During menu search, three types of patterns emerged: one where the mouse cursor remained still to the right of the menu and the first and only mouse movement started when visual search finished – *mouse on side* (MOS); one where the mouse cursor moved in syncrony with the eyes (sometimes 2 to 3 items behind the eyes) – *mouse with eyes* (MWE); and one where the mouse cursor stopped (hovering over) on a particular item and the eyes continued to scan the menu – *mouse hovering target*

(MHT). In the remaining trials (11.7%), participants exhibited a mix of these behaviours or a behaviour that was difficult to allocate to any of the above categories and this did not change with menu type. Results are shown in Figure 5.
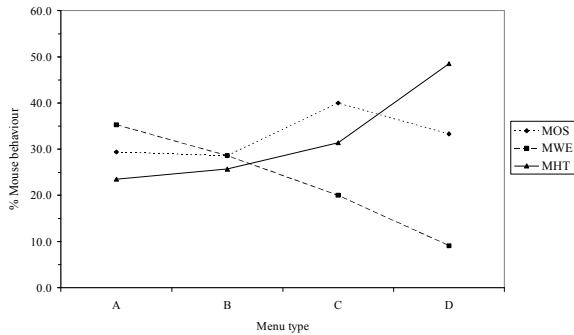

Figure 5: *Percentage of each type of mouse-movement pattern across menus, as a function of total number of trials.*

A Chi-square analysis showed that menu type and mouse behaviour do not appear to be associated (χ^2 = 10.076; df = 6; p > .05). As illustrated in Figure 5, this is likely to be caused by the erratic pattern of MOS. Both MWE and MHT follow clear linear trends in opposite directions according to the scent pattern of the menu items. This is shown by a significant relationship between menu type and mouse behaviour ((χ^2 = 8.965; df = 3; p < .05), when MOS is not considered. The more items competed with the target the more link "tagging" occurred and the less eye-mouse synchrony occurred.

Discussion

The results of Exp 1 demonstrate that eye-movement patterns are affected by the quality of the distracter items surrounding the target. As the number of distracters that compete with the target increases, search time increases, less items are skipped and overall scan patterns become more redundant. Results are in accordance with Brumby and Howes (2003, 2004) who showed that decisions about scanning the menus depends on the semantic characteristics of both the target and the distracters that surround it, and this can influence the number of items that are assessed before a decision is made. Results support a model of rational analysis (Cox and Young, 2004) which predicts that while searching for an item in a menu that might lead to the completion of a specific task, people make decisions based on a cost/benefit analysis. While searching a menu, people tend to choose an item that is likely to lead to goal completion when the costs of continuing to scan the rest of the menu are perceived as higher than the costs incurred by selecting that item. This would explain why in some situations, especially when most distracters are poor, the target item is selected without scanning the rest of the menu.

An eye-mouse link emerged in most trials (67.2%) where the mouse followed the eyes or hovered over an item whilst the eyes continued searching, which is in accordance

with the work of Chen et al (2001). In addition, mouse movements appeared to reflect the difficulty of the task and exhibit a pattern that is likely to assist "rational" eye searches. The mouse-movement behaviour patterns suggest that as uncertainty increases (i.e. the quality of the distracter items increases), participants tend to make more of use the mouse cursor to tag (by hovering over the link) potential targets whilst their eyes continue scanning through the menu.

Experiment 2

Method

Participants. Ten adults, 7 male and 3 female (mean age of 21.5 years), from the University College London volunteered to participate in this experiment. All reported normal or corrected-to-normal vision, and had 5 years or more of experience with the internet.

Procedure. The task was the same as in Experiment 1. However, this time, participants were instructed to click on a button at the top left corner of the screen, which would make the menu appear. Participants were told that they should keep that button pressed until they found the target. As soon as they chose their target, they should move the mouse rapidly and click on it. The data was filtered at a cut-off point of one second to make sure that the mouse could not interfere or aid visual search (although participants were unaware of this, since it would put an undesired emphasis on speed). Any trials where participants failed to click on a link within one second of releasing the button were considered time failure trials.

Stimuli and Materials. The stimuli and materials were the same as in Experiment 1.

Results

Target selection and search time. Participants selected the target item in 70.0% of the trials. In the remaining 30%, other items were selected in 54.2% of menus D, 18.8% of menus C, 20.8% of menus B, and 6.2% of menus A. Most of the alternative choices (41.7%) were rated 2 for information scent. Scent 3 and 4 distracters were chosen in 27.1% and 25.0% of the times, whereas scent 5 distracters were selected in only a small proportion of trials (6.2%). In general, selection accuracy was lower.

Participants did not click on a menu link within 1 second of menu onset in 18.1% of the trials. Neither these trials nor the ones where a distracter was selected will be considered in the following analysis, leaving 57.5% of valid data to be analysed.

In Exp 2, the main effects of menu type and target position on search time disappeared (F(3,82) = 1.168, p > .05 and F(1,82) = 2.475, p > .05, respectively).

To compare both conditions, a 4 (type of menu) x 2 (target position) x 2 (experiment) between-subjects ANOVA revealed that the participants that were allowed to move the mouse, were generally slower to make a selection

than the participants that had to rely solely on their eyes to perform the search (F(1,196) = 27.552, p < .001).

Number of items skipped. In contrast with Exp 1, the number of items skipped was also independent of the type of menu (F(3, 82) < 1). However, whether the target was positioned early or late in the menu had a similar effect as in Exp 1. On average, 4.6 items were skipped when the target was in position 3 and 2.8 items were skipped when the target was in position 8 (F(1,82) = 18.935, p < .001).

When comparing the number of items skipped in both experiments, no main effect was found (F(1,196) = 2.371, p > .05), i.e. participants that could move the mouse skipped the same amount of items on average as the participants that had their mouse movements restrained. However, a reliable three-way interaction between type of menu, target position and experiment revealed that in the menus where more distracters competed for the target (C and D) and where the target was positioned later in the menu (position 8), more items were skipped by the participants that could not move the mouse (F(3,196) = 5.428, P < .005).

Post-target visits. As in Exp 1, there was a main effect of menu type on post-target visits. However, in contrast to the participants that were allowed to move the mouse, in this experiment more post-target visits were made in menus that had poorer distracters (A and B) (F(3,82) = 3.271, p < .05). In addition post-target visits did not depend on whether the target was placed earlier or later in the menu (F(1,82) = 2.344, p > .05).

An ANOVA with experiment as an independent factor with two levels (1 and 2) also revealed that more post-target visits were made when mouse movements were allowed (F(3,196) = 5.976, p < .005). A two-way interaction between menu type and experiment was also reliable (F(3,196) = 14.622, p < .001) and revealed that menus containing more good distracters (C and D) produced more post-target visits when participants could move the mouse than when they could not. In addition, fewer post-target visits were made in menus with poorer distracters (A) when participants could move the mouse.

Given that a large proportion of trials were excluded due to time failures or inaccurate choices, the analyses were repeated for all the data where the target item was selected, i.e. including the time failure trial and similar results were obtained. In summary, when mouse movements were restrained, more items were skipped, less post-target visits were made, searches were shorter and accuracy decreased.

Discussion

These results show that when people are not allowed to move the mouse, search behaviour changes: eye-movement behaviour does not follow a "rational" pattern, target selection accuracy decreases and searches become faster. When not allowed to move the mouse, participants skipped more items when uncertainty was higher, i.e. when more distracters competed with the target, and this was especially

true when the target was positioned later in the menu. Within a rational framework, this behaviour is more characteristic of menus containing very poor distracters. In searches where mouse movements were allowed, participants could tag a potential target and scan the rest of the menu at will, which led to searches taking longer, more items being visited and choices being more informed. The decrease in accuracy and search time obtained in experiment 2 confirms this. Similarly, more post-target visits, which are characteristic of redundant searches uncertainty, were made when mouse movements were allowed. It appears that in the absence of the mouse cursor to assist search, behaviour approaches that of searches on "easy" menus, which incurs the risk of decreasing accuracy but carries a lower cost in terms of inspection time.

Restricting mouse movements using this method may change the nature of the task in unexpected ways (e.g. encouraging participants to trade off accuracy for speed). However, it is difficult to design an experiment that controls mouse movements but does not make the task somewhat artificial. Similar methods have been used to investigate mouse-pointing behaviour (e.g. Hornof, 2001) but further research is required to investigate the precise nature of the effect of the manipulation.

General Discussion

When people can move the mouse, eye movements behave in a way that is consistent with a rational analysis of search behaviour, because they depend on the overall scent pattern of the menu. In this scenario, the mouse movements observed in Exp 1 also appear to be "rational" since they exhibit a pattern that is somewhat dependent on the menu scent pattern. When more distracters compete with the target, both the observed eye- and mouse-movement patterns are compatible with the increase in uncertainty generated by those menus. Eye-movement scanpaths become more redundant (i.e. items are fixated multiple times) and a more thorough examination of the alternatives takes place. Mouse movements allow the "tagging" of certain options whilst the eyes are free to inspect the remaining options. The strategies employed during task completion result in an accuracy rate of over 92%.

When the mouse cannot be moved, eye-movement metrics do not appear to depend on the type of menu. Without the mouse, people are less accurate (70%) and faster than when allowed to use the mouse. These shorter inspection times in Exp 2 were somewhat surprising, given that in the absence of the mouse to assist search, longer inspection times were expected. According to Meegan and Tipper (1999), when distracters compete for visuomotor processing, an increase in response time occurs. This could account for the longer searches when mouse movements were allowed, given that in this case, distracters are all potential targets for action. When the mouse is held in place until the target is selected, processing of the distracter items may not include a motor component, shortening the total search time.

It could be that when people are unable to make use of the tagging strategies on which they usually rely, they are forced to fall back on a default strategy for completing these tasks. In this situation, behaviour is independent of the scent pattern of the menus. The participants' behaviour (more skipping under more uncertainty, fewer post target visits, quicker task completion) on all scent patterns is similar to the behaviour of the participants with menus type A in Exp 1.

Fu & Gray (2001) and Ballard et al (1995) have shown that people will choose the least cost/highest efficiency strategy for accessing information, choosing to rely on short-term memory rather than make a mouse click, or head movement. In their tasks, relying on short-term memory (STM) resulted in quicker but less accurate performance. In interactive search, people need to find out both *which* item has the highest information scent and *where* it is, so that, after assessing other items in the list, they can move the mouse to the high scent item and select it.

In Exp 2, participants also appeared to rely on eye movements alone rather than encoding the label and position of potential items in STM. Eye-movements are known to be less costly compared to the encoding of items in STM (230 ms on average for a saccade and fixation compared to 1,000 ms (Fu & Gray 2000)). With two items of information (scent and position of label) required to be stored in STM, it is likely that the 1,000 ms proposed in Fu & Gray is an under-estimation, thus making the eye-movement-only strategy even more efficient in comparison.

Without the opportunity to tag items of interest as they search the menu, people are encouraged to select a high scent item as soon as they see it. In these cases they may select an item that appears to be 'good enough' rather than exhaustively searching the menu to identify the item with the highest information scent. That is, without the benefit of the mouse to tag items of interest, people fall back on a satisficing strategy such as that proposed by MacGregor et al's (1986) model of single page menu search, rather than considering a number of potential items, storing them in STM and comparing them to each other.

In situations where users are able to use the mouse to support search, alternative strategies can be employed that offer higher levels of efficiency than eye movements only. These strategies facilitate multiple assessments of items and encourage "rapid and radical revisions of [..] estimates of the correctness of particular options" (Young, 1998) as in Cox & Young's model (2004). A tagged item is easy to locate with a single eye-movement. The additional costs of moving the mouse are outweighed by the perceived gain of greater accuracy. Thus, tagging an item facilitates almost simultaneous consideration of more than one item and enables people to avoid the often unsatisfactory satisficing strategy.

In accordance with Ballard et al (1995), our results suggest that visually marking an area to which we might want to return in the future incurs fewer costs in terms of memory storage and retrieval and increases efficiency.

Given the opportunity, people may choose this strategy over a satisficing strategy. This has clear implications for design. Providing features such as the "place marker" in the ISI Web of Science digital library is likely to prove useful for users performing interactive search tasks.

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