Eye tracking in Web search tasks: Design implications

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ABSTRACT

An eye tracking study was conducted to evaluate specific design features for a prototype web portal application. This software serves independent web content through separate, rectangular, user-modifiable portlets on a web page. Each of seven participants navigated across multiple web pages while conducting six specific tasks, such as removing a link from a portlet. Specific experimental questions included (1) whether eye tracking-derived parameters were related to page sequence or user actions preceding page visits, (2) whether users were biased to traveling vertically or horizontally while viewing a web page, and (3) whether specific sub-features of portlets were visited in any particular order. Participants required 2-15 screens, and from 7-360+ seconds to complete each task. Based on analysis of screen sequences, there was little evidence that search became more directed as screen sequence increased. Navigation among portlets, when at least two columns exist, was biased towards horizontal search (across columns) as opposed to vertical search (within column). Within a portlet, the header bar was not reliably visited prior to the portlet's body, evidence that header bars are not reliably used for navigation cues. Initial design recommendations emphasized the need to place critical portlets on the left and top of the web portal area, and that related portlets do not need to appear in the same column. Further experimental replications are recommended to generalize these results to other applications.

Keywords
Eye Tracking, Usability Evaluation, Software, World Wide Web

1. INTRODUCTION

1.1 Eye Tracking in Software Evaluation

Eye tracking has not been frequently employed in routine software usability evaluations, for several reasons. It is tedious, requiring extensive data reduction, and its focus on micro-level behaviors may be too narrow, considering the information desired from usability analyses. Eye tracking-based studies of search on user interfaces have necessarily been tightly constrained to specific stimuli [10], so that tasks are no longer similar to typical multi-screen search tasks such as web browsing. Within the rapid usability testing cycles of software industries, eye tracking is often viewed as a time-consuming methodology returning questionable benefits.

Eye tracking studies can be classified as top-down or bottom-up in their analyses. Top-down analyses essentially start with a cognitive or other goal-driven internal model [e.g., 11], then use eye tracking results to confirm or deny aspects of the model. This orientation relies heavily upon context and predefined objects within an interface. Bottom-up analyses attempt to develop behavioral inferences, starting from model-free eye tracking-derived data. For example, intent discrimination [16] applies statistical analyses to aspects of observed scanpaths, to guess the most reasonable of a small number of possible user choices. Application programs for bottom-up analysis of eye movements on displays are necessary if eye tracking will become a more routine methodology in usability evaluations.

There is a great need for studies that compare the results of traditional software usability assessments to those provided by eye tracking methods. As a start in this direction, Kotval and Goldberg [11] had a large sample of interface designers subjectively evaluate several different versions of a Windows™-based interface, in which the logical component groupings were manipulated. Participants then used each of these interface versions while their eye movements were recorded. They found several relationships between the subjective usability evaluations and the eye tracking-derived indices.

1.2 Dependent Measures

The present study considers results at three hierarchical levels: task, screen, and object. Each task contained multiple screens; some screens were required and others were unnecessarily visited by users. Each screen, in turn, contained several objects, or defined Areas of Interest (AOIs). AOIs are arbitrarily defined rectangular areas that contain objects of potential interest to the experimenter. For example, a marketing specialist might be

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interested in the total time that observers view the branding area (an object) on a home page. AOIs can surround any arbitrarily defined shape, such as common widgets or entire pages, given the limits of resolution of commercially available eye trackers.

Variables that are derived from eye tracking methods can provide insight into users' decision making while searching and navigating interfaces. Sequences of fixations (200-400 msec ocular dwells) and saccades (rapid eye movements between fixations) define scanpaths, providing a record of visual attention on a display. Although eye movement locations on a display are rather stochastic, regular scanpath sequences can be intermittently recognized [13]. There is a general recognition, for example, that the eyes are drawn to areas of greater information to observers [12]. However, informativeness has many dimensions, and is extremely hard to control in usability testing. Perhaps the most commonly used eye tracking information for usability purposes is dwell time within AOIs [2]. Dwell times can also be defined across screens or entire tasks. Several authors have previously compared the various ways that scanpaths, AOIs, and other metrics can be applied to usability evaluations [5, 6, 7, 8]. Users' strategies underlying menu search on displays is one area that has benefited from eye tracking-derived measures, especially by studying scanpath characteristics [1, 3].

One tool of great importance to these statistical methods is the transition matrix, which classifies preceding and succeeding AOIs, relative to a defined AOI [8]. Sparse transition matrices generally imply that search is relatively directed, whereas dense transition matrices imply relative random search, within some specific task or time interval. These matrices can provide a data representation that can also lead to the development of stochastic and queuing models of users' scanning on an interface [4, 9].

Three types of dependent variables were used in this study. *First*, users execute actions such as key-presses (e.g., page-up or page-down buttons) and mouse clicks on buttons, links, or other objects. These actions may or may not lead to screen changes, or they may modify other objects. *Second*, eye tracking-derived variables are defined that do not rely upon locally-defined context within a screen. These context-free measures consist of fixations, fixation durations, total dwell times, and saccadic amplitudes. Results derived purely from these measures are highly generalizable to other tasks and interfaces. *Third*, eye tracking measures can be defined relative to locally-defined AOIs. Dwell time within AOIs is an example of this type of measure. These results rely upon specific features or characteristics within an interface, and therefore are harder to generalize to other interfaces or tasks.

1.3 Markers of Task Difficulty

Several dependent measures provide the usability specialist with potential markers of search difficulty within a task. Repeatedly returning to a screen while searching for an object or link should eventually result in localized learning of an interface. Localized learning would result from internalized mental representations of the location of key interface features, such as key portlets, navigation links, and other informative areas. This learning is expected to be evident in shorter scanpaths, with fewer fixations and saccades. Search should also become more directed following page-up/page-down actions, than after clicking a link or button. Directed search is evident when observers scan between well-known object locations. Markers of directed search include long saccades, short scanpaths, and a compact search area. A page-up or page-down action, in this study, is executed when a user navigates a web page to view its upper or lower half. Although a new screen image physically appears, the underlying represented screen is really unchanged in the user's mind, given some familiarity with the screen. Page-up and page-down actions thus bring new areas of the current screen into view, as opposed to inserting an entirely new web page. Subsequent search should be fast and efficient to the extent that the user knows where features are contained following this action. Clicking links and buttons to bring up other pages should subsequently produce less efficient search, because the resultant objects and features will be less known to the user.

1.4 Portals and Portlets

Observed screens in this study were developed using a prototype version of Oracle Portal software. This software allows a user to

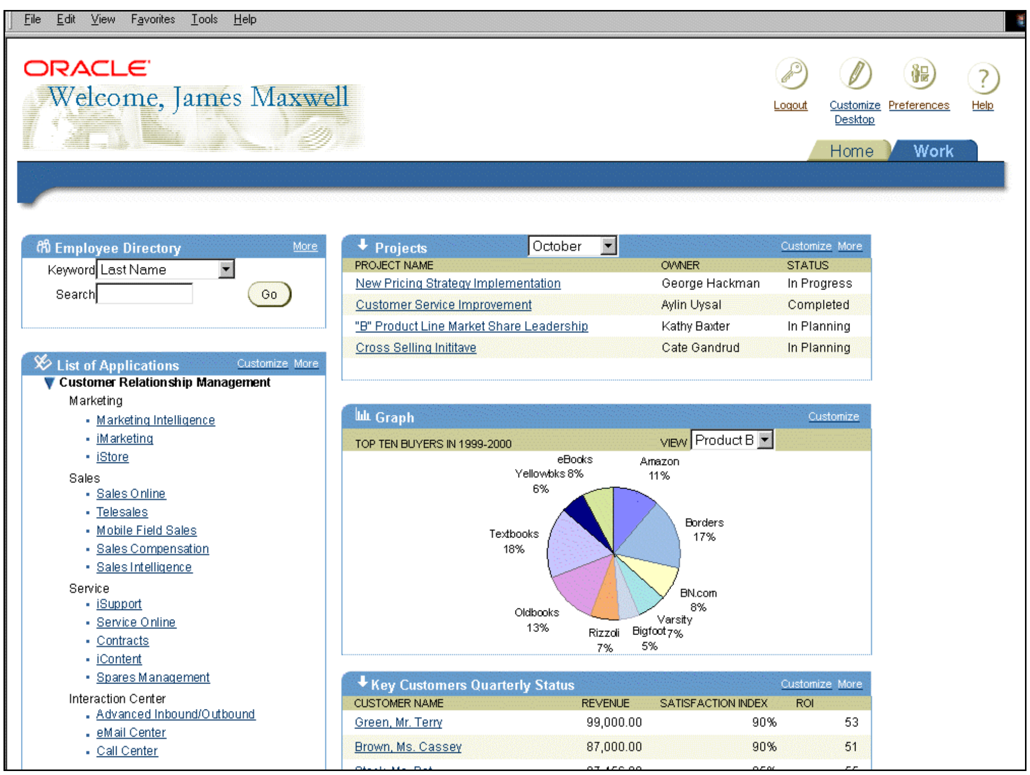

Figure 1. Opening screen, showing five portlets.

view web content through independent areas ('portlets') on a single web page. Each of these portlets can be created, deleted, moved, or modified by end users. In this study, participants started each of their tasks from the web portal view shown in Figure 1. A hypothetical user's name, James Maxwell, appeared at the upper left of the page, and five portlets were immediately visible on the first of two tabbed pages. Portlets displayed in Figure 1 include 'Employee Directory', 'List of Applications', 'Projects', 'Graph', and 'Key Customers Quarterly Status'. Each participant was instructed in the various components of the portal window, as well as the operations that were possible. Some, but not all, links and buttons within portlets were active for this study.

1.5 Objectives

The present study focused on unconstrained web search, by allowing users to navigate multiple screens while searching for specific information. In this somewhat unconstrained search environment, we sought to determine if any relationships exist between user actions, screen sequences, and eye movement-derived parameters. Observed trends will provide objective guidance for the use of eye tracking in multi-screen usability evaluations.

Patterns of fixating defined objects in web page search and modification tasks were studied, in order to develop design recommendations and improvements. This study was unique in that users were free to navigate multiple screens while eye tracking was conducted. Specifically investigated issues related to these tasks included:

- Whether eye movement-derived parameters were related to screen sequence or user actions preceding screen changes.
- Whether travel among portlets is biased towards horizontal versus vertical navigation.
- Whether objects within portlets, such as headers and links, are visited in any particular order.

2. METHODS

2.1 Participants

Seven adults (aged 18-45; three male, four female) were recruited from the San Francisco Bay area through either a community Internet bulletin board site, or a corporate database of current and potential users of Oracle database products. Users were screened for normal (or corrected to normal) visual acuity, and for no history of migraine headaches or epilepsy. Those with bifocals and contact lenses were not further considered, due to limitations of the eye tracker. All were familiar with PC/Windows™, and all had used the Internet Explorer web browser. All participants currently worked for medium to large organizations, and 4 out of 7 were familiar with Oracle Applications software. None of these participants had specific experience with the Oracle prototype software that was tested here; however one participant had personal or work related experience with similar software. Each was given a $100 gift certificate in compensation for the one-hour required period of time.

2.2 Apparatus

The study was conducted at Stanford University's Center for the Study of Language and Information (CSLI). The testing room contained experimenter and participant monitors, with adjustable chairs and tables. Adjustments were made to maintain the participant's eyes at 36 cm from the 17-inch monitor. A small tape recorder captured all comments by participants or experimenters. Eye movements were collected using an SMI EyeLink (SensoMotoric Instruments Inc., Needham, MA, Ver. 1.1) 250 Hz eye tracker. The EyeLink IVIEW on-line analysis software was responsible for low-level processing of blinks, saccades, and fixations. These were saved to files for off-line processing. A video scan converter also streamed the video image to a VCR for later analysis.

2.3 Task Scenarios

Three training tasks and six experimental tasks were conducted by each participant. In this study, *screens* denote single windowed views of web pages, whereas web *pages* refer to the entire contents of URLs. For example, page-up in this study produced a new screen image that is the upper half of the represented web page. All tasks represented activities conducted by an (hypothetical) Oracle Field Sales Representative ('James Maxwell') who handles sales accounts with international universities. Users' training objectives included learning to use the Tab function to navigate between the Home and Work tab pages, and to use the "More" hyperlink found in several portlets.

All six experimental tasks started with the screen that was shown in Figure 1. The objective of each respective task was to: (1) Find the "List of Applications" portlet, then use the "Hide & Show" tool, (2) Customize a portlet by subtracting items, (3) Remove a portlet, (4) Customize a portlet name, (5) Use the employee directory to get a phone number, and (6) Logout. The minimum number of steps (i.e., anything involving a physical response from a participant such as a mouse click or key-press) required to complete each task varied from 2 to 7, with a mean of 4.5. Participants were free to click links and page-up/page-down as needed. While this navigation freedom greatly complicated the present analysis, it added a high degree of reality to the tasks.

2.4 Procedure and Design

Each participant completed demographic, consent, and disclosure forms, then received an explanation of web portlets. After three training tasks, the eye tracker headband was mounted, followed by a short calibration procedure. Six experimental tasks were then presented in a fixed order. Participants were allowed to complete each task at their own pace, as long as all 6 tasks were completed within 20 minutes. Following the tasks, a post-task questionnaire and experimental debriefing were given. Participants could only use the page-up/page-down keys to move up/down each web page; the scrollbar was hidden. On each task trial, the experimenter read a short scenario that ended in a question or required task. The participant had to find the answer to the question by searching the web page over multiple screens, and following appropriate links. Trial timing started when the test administrator completed reading each question, and ended with the participant's successful completion of the stated task. Instructions stated that answers should be provided as quickly as possible without sacrificing quality.

2.5 Data Reduction

For each participant, video was analyzed to determine the start, end, and screen change times on each task. Any screens that appeared following accidental right-button mouse clicks were eliminated from further analysis. Three eye tracking data files were integrated for analysis of each task within each participant. *Fixation files* were constructed by SMI IVIEW software, using a minimum duration criterion of 200 msec with mean x/y location within a 10-pixel screen region for fixation definition [16].

Duration and x/y coordinates were available from each fixation. *Screen bitmap files* contained the color bitmaps of the 31 unique screens viewed by participants. Upper and lower halves of the same page were treated as separate screens for these analyses. Occasionally, participants repeatedly flipped between upper and lower screens of a represented page. *Object files* contained the vertices of experimenter-defined areas of interest (AOIs) for each screen within each task and participant.

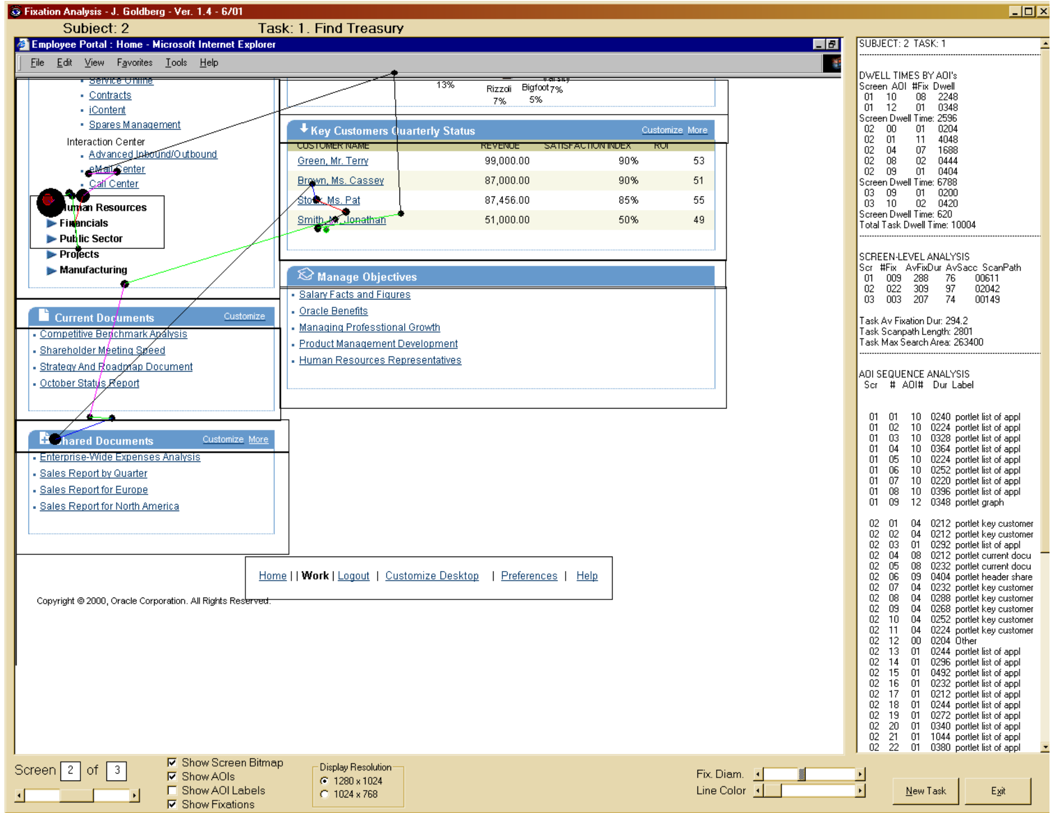

Figure 2. Analysis application interface, showing a participant's scanpath superimposed on a screen bitmap with AOI's indicated. Summary statistics are shown in the scrollable pane at the right. Screens can be stepped through using the scrollbar at bottom left of the window. Fixation relative diameters and line color can also be easily controlled via scrollbars.

A custom application was developed to effectively integrate these three files for data analysis. The user interface, shown in Figure 2, contains a main panel that displays the screen bitmap with fixations, scanpaths, AOIs, and AOI labels superimposed. Each of these features can be independently toggled. Within a task, the screens viewed by a participant can be stepped through in temporal sequence. Starting and ending fixations on a screen appear in green and red, respectively. The right-hand panel displays computed parameters within and across the screens of that task, for that participant. These include: (1) fixation dwell times within each AOI, (2) number of fixations, (3) mean fixation durations, (4) mean saccade durations, (5) total scanpath lengths within each screen, (6) sequence of AOI visits within each screen, (7) dwell times within each screen, and (8) an AOI transition matrix, showing the number of transition to and from each AOI on each screen.

The analysis program also contains a routine to detect and interpret situations with overlapping AOI's. These could occur spuriously from small, single-pixel overlap, or could purposefully occur when assigning an AOI within a larger AOI. When overlapping AOIs are detected on a screen, a popup dialog provides an easy means of assigning fixations to the appropriate and intended AOI.

3. RESULTS

3.1 Task Level

All participants completed the 6 tasks within the 20-minute time limit (mean = 11:05). The range of individual participants' task times was from less than 10 seconds to well over 6 minutes

From eye tracking data, mean within-task dwell time across participants was 24.4 sec, with a range of 2.6 to 61.5 sec. Note that median dwell time was only 11.5 sec, indicating that a few extremely long task dwells increased the overall average. The minimum dwell time within task and participant was 0.94 sec, and the maximum was 332 sec (over 5.5 minutes), but Levene's test indicated significant heterogeneity among variances. The Kruskal-Wallis non-parametric test showed that dwell times did indeed significantly differ among tasks (X^2_5=18, p<.01) but not among participants (p>.6). A decreasing trend in task dwell times was observed; this could have been a learning effect, as these tasks were always presented in a fixed order[1]. Overall task dwell time was predicted primarily by number of fixations, somewhat less by number of AOI visits, and little by fixation duration, according to stepwise regression analysis, $F_{1,36}$=7.6, p<.01. Note that fixation durations did not significantly differ among the six tasks (p>.05), although task 6 had somewhat longer fixations (349 msec) than the other tasks (283-298 msec).

Because of their generally positive correlation with immediately preceding fixation durations, saccades of longer amplitude may indicate that eye movement trajectories are more pre-planned than those of shorter durations. Greater pre-planning is one outcome of a better internal representation of the current interface. Saccadic amplitudes (in screen pixels) significantly differed among tasks ($F_{5,124}$=3.1, p<.01), but not among screen sequences

[1] Whereas a counterbalanced task order would have better enabled between-task comparisons, the need for a logical task flow precluded counterbalancing in this study.

(p>.1). Post-hoc Tukey intervals (p<.05) showed that Tasks 1 and 4 had shorter saccadic amplitudes (92-134 pixels) than Tasks 6 and 3 (198-242 pixels). Tasks 6 and 3 may have contained more salient features and targets to the participants than tasks 1 and 4.

Measured by summing saccadic amplitudes within a screen or task, scanpaths provide an indication of relative search efficiency. Within task and participant, mean task scanpath length increased with total number of fixations (r=.92, p<.01), number of screens used (r=.84, p<.01), and number of AOI visits (r=.82, p<.01). The scanpaths significantly varied across the six tasks ($F_{5,32}$=5.0, p<.01). Post-hoc Tukey comparisons (p<.05) showed that Task 6 scanpaths were significantly shorter, and Task 2 and 3 scanpaths were significantly longer than other scanpaths. From these data, differences in search efficiency were driven more by inter-task differences (p<.01) than by inter-participant differences (p>.5).

3.2 Screen Level

The number of visited screens provides another indication of search efficiency with a task. Participants visited a total of 215 screens across the six tasks. They visited 2 to 15 screens (mean 5.7) before completing each task, a significant difference ($F_{5,32}$=4.4, p<.01). Post-hoc Tukey intervals (p<.05) indicated that Task 6 had significantly fewer screen visits (2.4), and tasks 2 and 3 had significantly more screen visits (about 8.5) than the other tasks. The number of screens visited, however, did not significantly differ among participants (p>.1). Participants visited an average of 2.8 additional objects for each screen visited.

The ratio of actual number of screens visited to minimum number of screens required provides an indication of the difficulty of search within tasks. For example, a desired task link might be located on a second screen, requiring a minimum of one screen change and two screens to complete the task. If a participant actually required 5 screens to complete the task, the difficulty ratio would be 5/2 = 2.5. Table 1 shows these ratios. Since a page-down or page-up produced a new screen view, either of these was treated as a screen change. The average number of screens visited, across tasks, was 5.74, with SD of 3.45. Across participants, the difficulty ratios varied from 1.2 (easiest task) to 4.5 (most difficult task). Task 3, requiring only 3 actions and 2 screens, was clearly difficult, requiring 7 to 12 screens to complete, a significant difference, T_4=9.5, p<.001. Task 6, similarly, was the easiest task. Participants' actions to change these screens were approximately evenly split between page-up/page-down and clicking links or buttons.

Table 1. Actual Versus Required Minimum User Actions

Task	Actual : Min No. Screens	Ratio	Required User Actions*
1	4.6 : 2	2.3	**Page-down**, **Clk Button**
2	8.3 : 4	2.1	Clk Tab, Clk Link, **Clk Item**, **Clk Word**, **Page-down**, **Clk Button**
3	9.0 : 2	4.5	Clk Link, **Clk Checkbox**, **Clk Button**
4	5.5 : 3	1.8	Clk Link, **Page-down**, **Clk Item**, **Delete**, **Clk Button**
5	5.9 : 3	2.0	Clk Tab, Type Name, **Clk Button**
6	2.4 : 2	1.2	Clk Link, **Clk Button**

***Bold** actions lead to screen changes.

Participants returned to the same screen on relatively few occasions within tasks, as illustrated in Table 2, which shows the distribution of 215 screen visits by participants within tasks. From this table, there was one occasion where a given screen was visited 6 times within by a participant within a task. Conversely, here were 129 instances where a single screen was visited only once. Over half of all screen visits within tasks were not revisited again within that task. The mean number of times a screen was visited *within a task*, given that it was visited at least once, was 1.3, based upon this distribution. Independent analyses of the cases with at least 3 visits (2 screen revisits) within task and participant revealed no significant trend in dwell time, scanpath, or fixation durations across the screens.

Table 2. Distribution of Screen Visits

No. Screen Visits	Frequency
6	1
4	1
3	4
2	32
1	129

Across tasks, search may have become more directed as screen sequence increased. Mean scanpath length and dwell times appeared to decrease with screen sequence, but these trends were not significant whether task or participant was included as an independent variable in ANOVAs (p>.1).

Page-up/page-down actions essentially change the participant's view of a current screen. Logically, search behavior should be more directed following one of these actions, compared to search on an entirely new screen. To conduct this comparison, each screen visited by a participant was assigned a number indicating that it was a starting screen, a screen following a page-up/page-down, or a screen following any other user action. The present comparison is between the last two categories.
The number of unique AOIs visited significantly differed between tasks ($F_{5,209}$=3.5, p<.01), which reaffirms differences in search difficulty among the tasks. Post-hoc Tukey comparisons (p<.05) indicated that significantly fewer AOI's (1.2) were visited in Task 6 than in any other task. Participants made more AOI visits (2.8) in Tasks 1, 2, 4, and 5 than the other tasks. A 2-factor ANOVA, treating Tasks and User Action as factors, indicated that the User Action was not a significant main effect on number of AOIs visited (p>.2), but that the Task x Action interaction was significant ($F_{8,199}$=2.3, p<.05). Four tasks (2, 3, 4, and 5) contained instances of both page-up/page-down and clicks preceding screen changes. Of these, tasks 2 and 3 produced more AOI visits following clicks than page-up/ page-downs; tasks 4 and 5 reversed this trend. Thus, the notion that page-up/page-down results in more directed search than that following other actions appears to be task-specific.

Fixation durations significantly differed due to users' actions preceding each screen ($F_{2,202}$=4.0, p<.05). Post-hoc Tukey intervals (p<.05) showed that fixations on the first screen of a task were significantly longer (324 msec) than fixations on screens preceded by clicking links or buttons (282 msec). Screens preceded by a page-up/page-down action produced mean fixation durations (302 msec) that fell between these. The user's action preceding a screen visit may therefore signal differences in planning of scanpaths, as exhibited by differences in fixation duration.

3.3 Object Level: Between-Portlet Navigation

Within each screen, analysis at the object (or AOI) level focused upon which objects were visited and in what order visits occurred. For many tasks, observers travel from portlet to portlet when seeking a desired link. Eye tracking analysis can aid design recommendations by providing the natural search tendencies among portlets. A within-column search bias is evident if search moves vertically from portlet to portlet. A between-column bias exists if search moves horizontally among portlets. Whether search bias is within-column, between-column, or neither, should dictate the relative placement of portlets to enhance usability.

A portlet's body, its title, and any links in the header or body were treated as part of the same portlet group in the present analysis, to investigate users' navigation tendencies while searching for a specific link. In addition, only tasks and screens that required searching for a link contained in a portlet were included (Tasks 1, 2, 4, and 5; Home Tab page and Work Tab page). This analysis was carried out across these tasks to search for generalizable search behaviors that might apply to navigation among other portlets. The task pages that were selected here were all associated with similar search goals. The Work Tab page was previously shown in Figure 1. The first portlet visited on Home and Work pages is indicated in Figure 3 by percentage of first portlet visits. The Home page contained 10 portlets, whereas the Work page contained 8 portlets. Note that, in both pages, there was a greater chance (61%-79%) of starting with a portlet in the left column than the right column. In addition, it was more likely (59%-79%) to start in one of the upper two rows of portlets than in any of the lower rows.

Transitions among portlets were next considered. Given that a transition to another portlet occurred, the direction of that transition was tallied. Same column transitions occurred when moving up or moving down within a column of portlets, and cross-column transitions occurred when moving to the other column of portlets. Combining the transition results for the Home and Work screens, 58% of transitions from the starting portlet to a second portlet were made between columns, whereas 42% were made within the same column. Thus, there was a slight bias to visit a portlet in the other column, following the initial portlet visit on a screen. Extending this to the third portlet visited (or second transition), there was a slight bias (64% of second transitions) to stay in the same column if the first transition was within the same column. However, if the second transition was between columns, third transitions were equally likely between the same and across

A. Home Tab

9	24
17	9
17	2
17	2
2	2

B. Work Tab

18	7
48	7
11	7
2	0

Figure 3. Percentage (%) of Initial Portlet Visits within each screen, organized by relative location on screens. For example, the second portlet from the top on the left-hand side was the first portlet visited on 48% of occasions on the Work screen.

portlet columns. Because many participants didn't visit more than one portlet, there were insufficient data to break these trends down by participant.

Inter-portlet navigation strategy may change as participants become more familiar with a specific screen. To investigate this, transitions following the initial portlet visit were compared between Task 2 (an early task) and Task 5 (a late task). Within Task 2, the initial transitions were equally-likely between same-column and different-column portlets. However, in Task 5, there was a slight bias (64% of transitions) to visit a different column following the initial portlet visit. Further transitions, in Task 2, were similar to the initial transition, in that the next transition was likely within the same column if the last transition was within the same column. However, this didn't hold true for Task 5, in which the direction of further transitions was much more equally-likely between or within portlet columns.

Overall portlet navigation results indicated that observers are biased towards initially visiting portlets that are towards the left side, and in the upper-half of a page. Subsequent transitions to other portlets are slightly more likely to be to a different column of portlets, than to the same column. Follow-on transitions tended to continue this same strategy of same versus different-column visits.

3.4 Object Level: Within-Portlet Navigation

Eye tracking analyses have been used thus far to provide insight into how users interact with a product at several levels. Eye movements were first analyzed at the *task* level, followed by a focus on individual *screens* within those tasks. Next, attention was paid to those eye movements from *portlet to portlet* within those screens. Now we look at eye movements across *objects within a portlet*. An analysis at such a detailed level is more difficult because of the objects' small size. That is, this finer level of analysis is more prone to error, and the results are not as definitive. Nevertheless, within-portlet navigation is worthwhile to analyze because it at least shows a glimpse of the whole picture, from task, to screen, to portlet, to objects.

In this analysis, we looked at fixation transitions between three types of objects within a portlet: (1) the portlet header, (2) the customize-portlet link, and (3) the portlet body. Specifically, we wanted to know if there was a consistent navigation pattern. Figure 4 shows screens shots of three such portlets. Before an analysis was conducted, a hypothesis of navigation patterns was made to compare to actual scanpaths. For example, in Task 2 users were first expected to fixate the header to orient themselves, then fixate the content of its portlet body to verify that the "Wall Street Journal" link did exist, then fixate the right hand of the header to find the Customize link, then click on it.

Eye fixations were tallied from only those tasks in which clicking the Customize link was required to complete the task: Tasks 2, 3, and 4. In Task 2, participants were required to customize their Favorites portlet so that the "Wall Street Journal" link was removed. In Task 3, participants were asked to remove the Graph portlet from the portal. In Task 4, they were asked to change the name of the Notifications and Alerts portlet to just 'Alerts.'

Seventeen fixations fell within the AOI of the Customize link: 7, 2, and 8, for each respective task/portlet. It is understandable that such a low quantity of fixations fell within these AOI's because they are comparatively small, having a lower probability of

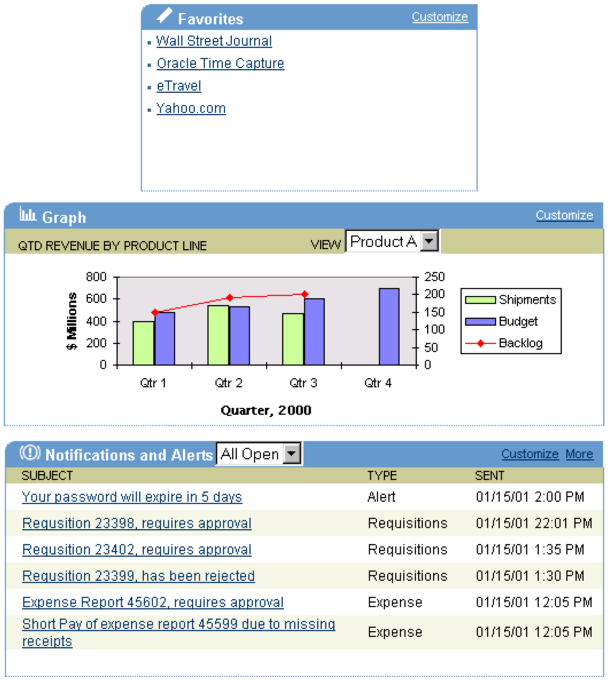

Figure 4. Screen shots of 3 portlets from the Home Tab page: Favorites (top), Graph (middle), and Notifications and Alerts (bottom).

containing fixations. All but one navigation pattern fell into one of two categories. Participants either showed the hypothesized pattern of **Header-Body-Customize** (3 occurrences), or showed a slightly different pattern, **Header-Customize** (3 occurrences), in which the portlet body was not viewed before the Customize link.

A clearer pattern of transitions among these objects is required before any design recommendation changes can be supported. It would be interesting to compare the current design to one that placed the Customize link below the content in portlet body. Such a design may enable users to find the Customize link easier because their navigation pattern of viewing header (orientation), content (verification), and customize link (action) would be a short straight line. However, it is possible that the original design would be preferred because it does enable experienced users who do not need verification to skip the portlet body.

4. DISCUSSION

The present study gathered eye movement information while individuals navigated a prototype Oracle web application in six specific tasks. These tasks involved editing and maintenance activities to links and objects within portlets. Most required 4 or 5 user actions, such as clicks or selections, that were contained within 2 or 3 screens. Participants navigated through multiple screens with few restrictions as they interacted with the site. Multiple screens present great challenges to eye tracking studies with little control over stimuli and screen objects. This study provides a foundation for future multiple-screen eye tracking studies, and addresses specific issues as an illustration of the utility of eye tracking for usability analysis.

Results in this study were presented in a hierarchical manner. First, task-level results sought differences in performance and complexity among the six tasks. Next, screen-level analysis investigated the screens visited within each task. Next, the object-level analyses were concerned with specific objects (AOIs) that were fixated within each screen, with a focus on transitions among portlets. Finally, a second approach object-level analysis was considered, by investigating the fixation order of objects defined within specific portlets.

Between-task differences were generally stronger than between-participant differences in the eye tracking-derived parameters. While one participant required over 5 minutes to complete one of these tasks, most completed each task in less than 30 seconds. Because the six tasks were always presented in the same order within-participants, a possible learning effect was noted across the tasks.

Based solely on eye tracking data, some tasks were more easily and efficiently performed than others. Tasks 3 and 6 had longer saccadic amplitudes than tasks 1 and 4, indicating a stronger mental representation of salient components in the former tasks. Task 6 scanpaths were much shorter than task 2 or 3 scanpaths. Similarly, task 6 required less then one-third of the screens required by tasks 2 or 3. Thus, eye tracking data showed that task 6 was clearly a more efficient task, whereas tasks 2 and 3 were more tedious for the participants .

The ratio of actual number of screens visited to minimum number required to complete a task is a secondary measure of task difficulty. This ratio was greatest (4.5) for task 3, and the smallest for task 6, in agreement with the above eye tracking-derived results. The ratios from the remainder of the tasks were quite similar, in the range of 1.8 to 2.3. Note that these ratios could also be constructed at deeper levels, such as required:actual AOIs visited; these were not developed for the present paper.

The impact of screen sequence was considered here as a potential influential factor on directed search. Highly directed search on displays can be noted by short scanpaths, with few fixations [6, 8]. Most screen visits by participants were to novel screens that had not been previously observed. Given that a screen had been previously observed within a task, there were only six instances across the participants that it was viewed again. These screen revisits were conducted during participants' search for specific objects, but there was little evidence that search became more directed as participants returned to the same screen within a task. While still an issue for further investigation, there is presently too little evidence to support the notion of more directed search as screens are revisited. This result implies that participants may have had a poor mental representation of objects and portlets within already visited screens. Inconsistent logical organization of portlets or other objects with low saliency could both cause this finding.

Participants' actions preceding each visited screen provided an additional way to study the issue of directed search behavior. Navigation could be considered to be within-screen if using page-up or page-down. This navigation allows participants to use on-screen objects as cues to the location of desired objects following the page-up/page-down, and therefore should be relatively directed. Navigation by clicking an on-screen object (i.e., a link or a button) leads to an entirely new page (which may or may not be familiar to participants), and should therefore lead to less directed search due to fewer known cues. Fixation durations were somewhat related to these user action differences, in that first-screen fixations were quite a bit longer than those following link or button clicks. However, the fixation durations following page-up/page-down were not uniformly longer than those following other actions. Although some significant differences were noted within tasks, the notion that search was more directed following page-up/page-down than other screen-changing user actions was generally not supported. This implies either that participants were not forming adequate mental representations of objects on presented web pages, or that they were not using well-formed mental representations. It is possible, for example, that the number of links and other objects contained on these pages precluded the formation of an adequate mental representation over the time period of this study.

Navigation among portlets was studied by considering all portlet headers and portlet header links as belonging to portlet bodies. This enabled the study of which portlet participants initially visit, and a determination of what direction subsequent navigation moves. The portlets were contained on the two most commonly visited screens, Home and Work, to ensure that sufficient data was available for analysis. The first portlet visited was usually on the left-side or top of these screens. Subsequent navigation was then slightly more biased towards crossing to the other portlet column, than to search portlets within the same column. The tendency to cross columns may have increased with familiarity. Clearly, design recommendations should emphasize that important portlets should initially be contained on the upper-left or top of screens, to minimize search time.

Navigation within portlets was studied by focusing on fixations within portlet bodies, their headers, and any portlet header links. Specifically, the location of the customize link was considered, relative to the portlet body and header. As results for fixation order among these objects were mixed, it is recommended that either the Customize link should not be moved from its current location, or that an additional Customize link be added to the bottom of the portlet body.

This study affirmed the utility of eye tracking data as an additional source of information in a usability evaluation. It is hoped that future studies will add to the relatively small body of work that associates usability results with eye tracking results. Although data reduction and metric computation is tedious, insights may be provided that are otherwise unavailable. Assessment of scanpaths and AOIs visited on screens, for example, provides search efficiency information that goes well beyond that provided by task completion time. Micro-strategies, such as fixation order within defined objects on a screen, were studied here, to provide potential design recommendations.

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