

Effects of navigation aids on web performance in younger and older adults

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C.E. Hudson, C.T. Scialfa, R. Diaz-Marino, J. Laberge, S.D. MacKillop. Effects of navigation aids on web performance in younger and older adults. Gerontechnology 7(1):3-21. Age-related differences in web navigation were examined in two experiments, one (N=44) examining search performance and memory for site structure and a second (N=61) investigating search and memory for site content. Participants searched a large website under one of two experimental conditions; a control condition with only basic navigation aids or a condition with more enhanced navigation aids available. In Experiment 1, the enhanced navigation aids were breadcrumbs and a dynamic side-tree (BC-DST), whereas in Experiment 2 only the dynamic side-tree (DST) was available. In Experiment 1, search was more efficient for both age groups in the BC-DST condition. Age differences in search time and recall of the website's structure could be eliminated by controlling for working memory and processing speed. In Experiment 2, navigation speed improved with practice and there were larger improvements observed for older adults. Navigation tools did not improve performance in either age group. Younger adults had better memory for content than their older counterparts. Contrary to the hypothesis that older adults are more frequently 'lost' in their search, age was not associated with the number of pages or repeat pages visited. Future research should focus on alleviating cognitive demands of search in more representative groups of older users.

Keywords: web navigation, adults, age differences, memory, navigation speed

Most Internet users browse the World Wide Web (WWW) at least once per day¹ and, increasingly, these users are older adults^{2,3}. As an illustration, in the year 2000, Canadians over 60 represented the

fastest growing group of Internet users⁴ with nearly half of them using it daily⁵. Similar trends have occurred in countries such as the United States⁶.

Age and navigation aids

Navigating this resource can be daunting. Older adults often experience more problems than the young² associated with finding broken links, viewing graphics, finding new information, and revisiting pages or sites¹. Although younger and older adults have similar positive attitudes towards the WWW, older adults are more negative when it comes to difficulties encountered while learning to use it⁷. Navigation aids may ease such difficulties by providing assistance to users in finding what they are seeking.

In the present study we investigated the role of two different navigational aids in searching the WWW. First, we begin with a discussion of the navigation aids used in the current study. Next, we examine predictors of navigation performance and how they relate to aging. Finally, we will provide a brief overview of Experiments 1 and 2.

NAVIGATIONAL AIDS

A typical web page, consisting of a banner, side-menu and content area is shown

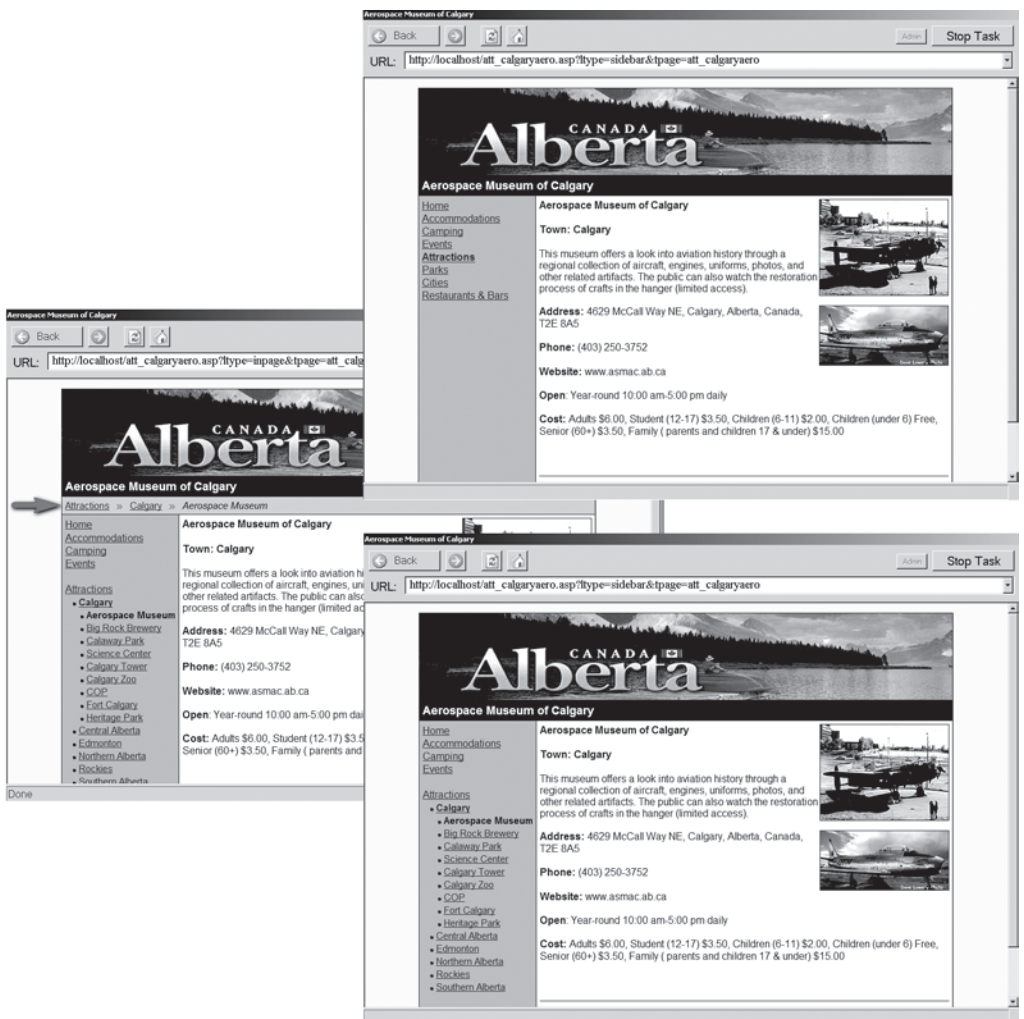


Figure 1. Screenshots of the web format conditions used. Top is the control condition used in Experiments 1 and 2 with only a static side-bar menu. Middle is the BC-DST condition used in Experiment 1 with both the breadcrumb trail (indicated by the arrow) and dynamic side-tree menu. Bottom is the DST condition used in Experiment 2 with only a dynamic side-tree menu

in Figure 1. Difficulties in WWW navigation are often characterized by problems searching for information and/or getting lost⁸⁻¹⁴. Navigation tools that reduce the probability of getting lost or disoriented should enhance overall usability. A variety of other navigation aids can be incorporated into the design by the web browser (for instance, the back button) or by the website itself (for instance, hyperlinks). The current study examined two navigational aids, breadcrumbs and dynamic side-trees.

As shown in Figure 1 (middle), breadcrumbs indicate the user's current location as well as a portion of the website's structure in a horizontal fashion (Attractions → Attractions in Calgary and area → Aerospace museum of Calgary). There are reasons why breadcrumbs may be more useful than alternatives like the 'back' button. They locate the user within the structure of a website and offer 'shortcut' links for a user to move to relevant locations in fewer steps. By traversing from one page to another in fewer steps, breadcrumbs are believed to result in more efficient navigation¹⁵⁻¹⁷. These attributes are also consistent with general design and usability principles such as minimizing the user's memory load, providing feedback, and providing shortcuts to speed up the interaction for advanced users¹⁸. More details about breadcrumbs have been discussed by Nielsen¹⁹.

Dynamic side-trees can be best understood in contrast to the static side-bar shown in Figure 1 (top). Static side-bars allow users to select a main topical link and navigate towards it. The static side-bar provides some organizational information about the website's structure, but only the main topical categories. In Figure 1 (middle and bottom), dynamic side-trees can expand or collapse subcategories related to the main topical categories. Dynamic side-trees might enhance navigation for a number of reasons. They are incorporated

into an existing navigation menu, with which users are already familiar and attentive²⁰. More structural information is visible to the user and so they can navigate in fewer steps. Such advanced features can enable web users to accelerate habitual navigation actions like backtracking, a frequent behaviour when searching the WWW^{12,20}.

In addition to facilitating search directly, breadcrumbs and dynamic side-trees are also believed to lessen cognitive demands during navigation²¹. With topological information visually available, the need to remember the website's organization is lessened. Thus, mental resources can be reallocated elsewhere. This may be particularly beneficial to older users.

PREDICTORS OF NAVIGATION PERFORMANCE

There are a number of predictors of web navigation explored in the aging and technology literature including spatial ability²², perceptual speed^{21,23}, memory^{21,23}, anxiety^{21,23}, and computer self-efficacy²³. Because of their centrality to theories of cognitive aging and because they have been implicated as important to web performance generally²¹, we chose working memory and processing speed as our two main cognitive predictors.

Salthouse^{24,25} described working memory as the active storage and manipulation of information to perform a task. Working memory is reduced in older adults, particularly when manipulation is required²⁶. Searching the WWW is thought to demand a significant amount of working memory^{7,21} for both navigation and comprehension¹¹. Hawthorn²⁷ advised that computer interfaces should provide users (particularly older adults) opportunities to off-load memory requirements to the program. Minimizing the user's memory load is also a key design principle¹⁸.

Mead et al.²⁸ compared younger and older adults in a series of web tasks and found

that older adults took more time and were less likely to successfully complete all the tasks, returning to previously visited pages more often than the young. Search inefficiency in older adults appeared to be associated with trouble remembering which links were previously accessed and the type of information on those previously viewed pages.

Laberge and Scialfa²¹ examined the relations between various individual difference variables and web navigation performance. They found that working memory accounted for variation in the total number of pages visited and the number of pages re-visited. In addition, memory for website links and related categories was correlated with measures of working memory. Thus, individuals with strong working memory abilities not only have better general navigation performance, but also acquire more knowledge about the website's organization. Laberge and Scialfa suggested that navigation aids such as breadcrumbs can off-load requirements of working memory to improve web navigation performance. One of the goals of the present study was to explore this hypothesis directly.

In Experiment 1, participants searched web pages in one of two web navigation formats: the first served as our control condition with no navigation aids while the second condition included both breadcrumbs and dynamic side-trees (BC-DST). We expected search performance and memory for the site's structure to be better for participants using the BC-DST condition. Older adults were predicted to take longer to complete the tasks and to experience more disorientation than their younger counterparts. We also hoped to duplicate findings from Laberge and Scialfa²¹ that factors like working memory and processing speed are linked to the age-related variance in performance. Importantly, we predicted an interaction between age and navigation aids whereby age deficits would be less in the BC-DST

condition because of its reduced working memory demands.

Based on the findings from Experiment 1, the second experiment had participants search web pages for two sessions in either a control condition or a condition that only included the dynamic side-trees (DST). Performance and memory for site content were predicted to improve with practice, and to be better in the DST condition, particularly with older adults.

EXPERIMENT 1

Method

Participants

There were 44 paid (\$15 CDN) volunteers in this study, recruited from the University of Calgary area. Participants were fluent in English, community-dwelling, free from serious medical conditions and, by self-report, were not taking medications that impaired memory or concentration. They were experienced with using computers, the WWW, and a mouse and keyboard. Everyone had a visual acuity of 20/40 or better at the 50 cm test distance ($M=1.08$ minutes of arc, $SD=0.12$ minutes of arc). There was group equivalence across age and web format conditions on demographic variables such as education level, gender, etc. The only exceptions were age differences found in computer/WWW expertise and background knowledge of Alberta (*Table 1*).

Apparatus and Materials

Most tasks were completed using a personal computer (AMD Athlon XP processor at 1.8 GHz with 1.0 GB of RAM) and shown on a 17 in. (43.18 cm) LG Flatron monitor set at a resolution of 1024 X 768 pixels. Participants used a standard keyboard and a Microsoft Optical Wheel Mouse to make responses.

The web task was completed using a custom web browser (*Figure 1*). The browser contained six buttons, including back, forward, refresh, home, start, and stop. It did not include any additional navigation aids

Age and navigation aids

Table 1. Means and standard deviations (SD) for participant demographics; TP = target present; WM = working memory; italics: $0.01 < p \leq 0.05$ (one-tailed); bold: $0.001 < p \leq 0.01$ (one-tailed); underlined: $p \leq 0.001$ (one-tailed); P-values for differences between young and old are one-tailed because in most cases the directionality of the relation is known

Variable	Experiment 1		Experiment 2	
	Young (n=24)	Old (n=20)	Young (n=31)	Old (n=30)
Females	15	16	16	18
	Mean SD	Mean SD	Mean SD	Mean SD
Age, yrs	<u>19.96</u> 1.76	<u>61.20</u> 5.85	<u>22.79</u> 4.17	<u>63.03</u> 6.18
Education level, yrs	14.58 1.41	15.22 3.47	15.76 1.99	16.00 2.44
Health, 1=Very poor to 5=excellent	4.38 0.58	4.00 0.65	4.26 0.77	4.23 0.77
Computer experience, yrs	<i>10.29</i> 2.49	<i>15.10</i> 8.79	<i>11.43</i> 3.59	<i>14.99</i> 6.89
Computer use, hrs/week	19.50 11.69	10.15 10.12	25.01 13.70	14.68 10.65
Email use, hrs/week	3.42 2.25	3.71 3.76	4.72 2.49	5.82 5.24
WWW experience	0.29 0.98	-0.34 0.94		
WWW usage			<u>0.70</u> 0.89	<u>-0.72</u> 0.43
WWW expertise			-0.26 1.03	0.27 0.91
Using the WWW, yrs	6.50 2.36	8.20 5.40	7.35 1.94	8.20 3.49
Web use, hrs/week	11.33 8.06	4.73 4.66	<u>15.85</u> 10.74	<u>3.60</u> 3.52
Websites visited / week	<u>20.90</u> 25.17	<u>10.33</u> 14.01	<u>17.27</u> 13.59	<u>8.02</u> 6.06
Website developed	0.79 1.02	0.20 0.70	<u>0.95</u> 1.07	<u>0.01</u> 0.03
Live knowledge	<u>-0.52</u> 0.38	<u>0.62</u> 1.16	<u>-0.57</u> 0.67	<u>0.59</u> 0.95
Travel knowledge	0.21 0.96	-0.25 1.02		
Living in Alberta, yrs	<u>13.63</u> 7.76	<u>36.80</u> 15.79	<u>12.98</u> 8.42	<u>31.24</u> 15.65
Number of cities/towns lived in	7.33 0.92	2.20 1.85	1.25 0.50	1.84 1.09
Traveling Alberta, days/yr	18.73 18.61	11.95 14.36	<i>11.87</i> 8.30	<i>18.18</i> 13.70
Number of cities/towns visited	9.35 6.57	27.60 28.26	<u>7.07</u> 4.83	<u>14.25</u> 8.99
Events attended / year	1.69 1.02	2.40 2.50	1.96 1.37	2.35 1.56
Visuospatial WM, time in s	<u>85.38</u> 21.01	<u>133.00</u> 43.74	<u>81.31</u> 14.97	<u>133.07</u> 30.65
Visuospatial WM, % efficiency	<i>38.08</i> 7.12	32.25 9.81	<u>37.43</u> 5.50	<u>31.60</u> 7.51
Processing speed, TP; ms	<u>1332.68</u> 183.13	<u>2091.13</u> 290.80		
Trails B, time in s			<u>57.36</u> 15.16	<u>81.93</u> 23.81

(such as a history feature or favourites). 'Start' and 'Stop' buttons were pressed at the beginning and end of each navigation task to determine task completion times.

The Travel Alberta website developed by Laberge and Scialfa²¹ was used in an updated form. It had a semi-rigid hierarchical structure²⁹ with seven main navigation links; accommodations, camping, events, attractions, parks, cities, restaurants and bars. These links were located in the navigational menu and outlined the overall structure of the site. There was a maximum depth of five 'clicks' from the homepage.

The website contained a total of 420 pages, with an average of 117 words per page (range=52-711). All pages were designed using a common template that

was divided into three regions; header (approximately 880 x 175 pixels), navigation area (approximately 220 pixels wide), and content area (approximately 660 pixels wide). Following usability guidelines²⁹, approximately 65% of the page was filled with text and graphics, 20% was used for navigation, and the remaining 15% was white space. All text was presented in 14-point sans-serif font. All unvisited navigation links were underlined and in blue whereas visited links were underlined and in purple.

The site was presented in two different web formats. The control condition (Figure 1, top) had the same layout as that used by Laberge and Scialfa²¹. It contained a static side-bar with links to the seven main categories. In the BC-DST condition, breadcrumbs and a dynamic side-tree were

available (*Figure 1*, middle).

WWW experience was measured with four questions; the number of hours per week spent using the WWW, the number of years using the WWW, the number of websites developed, and the number of different websites visited per week. Subject matter knowledge was measured with five questions; years living in Alberta, days per year spent traveling in Alberta, different Alberta cities/towns lived in, Alberta cities/towns visited, and events attended per year in Alberta. These data were subjected to separate principal component analyses. For subject matter knowledge there were two components accounting for 61% of the variance. The first component reflected participants' general knowledge and experience of living in the province. The second component reflected travel habits and general geographic knowledge of Alberta. For WWW experience, we found one significant component that accounted for 50% of the variance in all the questions.

Verbal working memory was estimated with a reading span test²⁵. Visuospatial working memory was assessed with a variant of the 'Concentration' game³⁰ in which participants must remember object identity and spatial location while also processing new information. We chose this measure due to its availability at the time and because it has been used in our previous work²¹. Reaction times for triple-conjunction search were used to index processing speed (for details see Ho et al.³¹).

Procedure

All participants were tested in a 90-min session that was approved (as was Experiment 2) by the Conjoint Faculties Research Ethics Board of the University of Calgary. After providing their signed consent, participants completed a computer and WWW experience, and a demographic questionnaire. Next, we assessed visual acuity, followed by tests of processing

speed, verbal and visuospatial working memory, the web task, and finally a test of recall for the hierarchical structure of the website.

The web task required participants to find answers to 30 questions such as "What are the current hours of operation for the Aerospace Museum of Calgary?" that could be found on only one page of the website. Each question was presented singly and participants pressed the start button on the browser to begin. After finding the answer to the question and reporting it verbally to the experimenter (who confirmed the accuracy of the response), the participant pressed the 'stop' button to end the trial. Because completion time was a criterion variable, participants were told they could not ask questions once the 'start' button was pressed but could ask questions between trials.

There were 2 practice and 30 experimental trials. Experimental trials were grouped by category (for instance, 'attractions' or 'accommodations') to maximize benefits that may be seen from using either the dynamic side-tree or breadcrumb tools. With questions grouped by category, participants using the navigation tools could traverse between pages in fewer clicks than if they did not use these tools. Specific questions within categories and the category order were randomized.

After completing the web task, participants were asked to recall the names of the links and categories that made up the hierarchical structure of the website. After viewing the example of a tree-like structure, participants drew the names of links and categories in a similar tree-like manner. They were not made aware of the memory task until after they had completed the web task. Performance was measured based on the following scoring system, which was designed to maximize credit for any partial recall while still penalizing for guessing:

- (i) One-half point for the correct name of a link or category;
- (ii) One-half point for correct superordinate location in the hierarchy;
- (iii) Loss of one point for incorrect links or categories (i.e. for including 'The Banff Springs Hotel' when it is not a mentioned Hotel on the site);
- (iv) Loss of one-half point for repeated incorrect links or categories (i.e. multiple instances of 'restaurants' when there is only one).

Results of Experiment 1

The analyses focus on three performance measures: time, total number of pages visited, and number of repeat pages per trial. We chose these performance measures because they are sensitive to the effects of disorientation in hypertext navigation³²⁻³⁶. Table 2 gives the means and standard deviations for the performance measures. Additionally, we examined age and format differences on recall of the website's structure. Because of the large number of analyses involved, we report only significant effects in abbreviated form.

Age x web format x order analyses of variance

For search time, only the main effect of age was found, $p < 0.001$; $\eta_p^2 = 0.55$. On average, younger adults ($M = 21.93$, $SD = 4.56$) finished trials faster than older adults ($M = 34.75$, $SD = 7.73$). The remaining main effects ($ps \geq 0.41$; $\eta_p^2 \leq 0.02$) and higher order interactions ($ps \geq 0.07$; $\eta_p^2 \leq 0.09$) were nonsignificant.

For the total number of pages visited, only the main effect of web format was obtained, $p < 0.001$; $\eta_p^2 = 0.37$. Participants who used the BC-DST format visited significantly fewer pages ($M = 4.16$, $SD = 1.17$) than participants who used the control format ($M = 5.78$, $SD = 1.27$). The remaining main effects ($ps \geq 0.07$; $\eta_p^2 \leq 0.09$) and higher order interactions ($ps \geq 0.24$; $\eta_p^2 \leq 0.04$) were nonsignificant.

For the number of repeat pages visited per trial, only the main effect of web format was discerned, $p < 0.001$; $\eta_p^2 = 0.42$. Participants who used the BC-DST format visited fewer repeat pages ($M = 1.70$, $SD = 1.05$) than participants who used the control format ($M = 3.27$, $SD = 1.06$). All other main effects ($ps \geq 0.06$; $\eta_p^2 \leq 0.09$) and higher order interactions ($ps \geq 0.19$; $\eta_p^2 \leq 0.05$) were nonsignificant.

As expected, younger adults ($M = 40.94$, $SD = 14.62$) had a better memory for the website's hierarchy than older adults ($M = 23.48$, $SD = 9.84$), $p < 0.001$; $\eta_p^2 = 0.42$. There was also a significant main effect of order, $p = 0.04$; $\eta_p^2 = 0.11$. Participants given the first trial order had worse recall ($M = 29.78$, $SD = 14.14$) than those who used the second ($M = 35.69$, $SD = 16.02$). This effect did not interact with other variables.

Memory scores also revealed an age x web format interaction, $p = 0.05$; $\eta_p^2 = 0.10$. Further examination showed that for younger adults, memory was equivalent in the BC-DST condition ($M = 43.04$,

Table 2. Means and Standard Deviations (SD) for performance measures in Experiment 1; BC-DST = breadcrumb - dynamic side-tree condition

Variable	Younger persons				Older persons			
	Control (n = 12)		BC-DST (n = 12)		Control (n = 10)		BC-DST (n = 10)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Time / trial	22.15	3.31	21.71	5.70	34.22	7.38	35.27	8.43
Repeat pages / trial	3.29	1.33	1.67	1.02	3.24	0.68	1.75	1.14
Total pages / trial	5.88	1.60	4.25	1.21	5.67	0.79	4.06	1.17
Website structure memory	38.83	12.87	43.04	14.62	28.60	10.72	18.35	5.56

Age and navigation aids

Table 3. Correlation matrix for predictor variables in Experiment 1; *a* = Point-biserial correlation; *italics*: $0.01 < p \leq 0.05$; **bold**: $p \leq 0.01$; *P*-values for differences between young and old are one-tailed because in most cases the directionality of the relation is known; TP = target present; WM = working memory

Variable	Variable												
	1	2	3	4	5	6	7	8	9	10	11	12	
1 Age	-												
2 Gender ^a	.22	-											
3 Web Format ^a	.03	-.05	-										
4 Education, yrs	.07	-.21	.11	-									
5 Live knowledge	.51	-.06	-.04	.27	-								
6 Travel knowledge	-.21	.07	-.22	-.03	.00	-							
7 WWW experience	-.31	-.42	-.02	.27	-.14	-.18	-						
8 Verbal WM	-.49	.09	-.08	.08	-.19	.17	.26	-					
9 Visuospatial WM, time	.69	.29	.06	-.09	-.32	.01	-.20	-.40	-				
10 Visuospatial WM, efficiency	-.45	-.24	-.03	.15	-.10	.06	.03	.21	-.86	-			
11 Processing speed (TP)	.85	.26	-.13	.08	.49	-.16	-.37	-.42	.62	-.43	-		
12 Trial order ^a	.11	-.19	.00	-.09	-.24	-.07	.02	-.26	-.09	.08	.07	-	
13 Website structure memory	-.58	-.22	-.08	.01	-.29	.15	.30	.42	-.49	.26	-.50	.19	-

SD=14.62) and the control condition ($M=38.83$, $SD=12.87$), $p=0.49$; $\eta_p^2=0.02$. For older adults, the effect of Web Format was found to be significant, $p=0.02$; $\eta_p^2=0.29$ but, contrary to our expectations, older participants in the BC-DST condition ($M=18.35$, $SD=5.56$) scored significantly lower than in the control condition ($M=28.60$, $SD=10.72$). All other higher-order interactions ($p_s \geq 0.08$; $\eta_p^2 \leq 0.08$) and the main effect of web format ($p=0.42$; $\eta_p^2=0.02$) were nonsignificant.

Proportion of navigation methods used

The percent of navigation tools used by younger and older adults for the two web formats was also examined. An age x web format ANOVA revealed no significant main effect or interaction involving age for any of the navigation methods used ($p_s > 0.18$; $\eta_p^2 \leq 0.04$). Web format effects were observed for the back button (control=19.6%, BC-DST=9.7%; $p=0.004$; $\eta_p^2=0.19$), menu; that is, use of either static side-bar or dynamic side-tree (control=19.9%, BC-DST=46.9%; $p < 0.001$; $\eta_p^2=0.60$), and in-page clicks (control=60.5%, BC-DST=43.1%; $p < 0.001$; $\eta_p^2=0.62$). Participants in the BC-DST con-

dition relied more on the dynamic side-tree while those in the control format relied more on the back button and in-page links. On the other hand, the breadcrumb tool was seldom used ($< 1\%$).

Correlations among variables

The inter-correlations among predictors are shown in Table 3. As expected from past research, increased age was associated with less WWW experience¹, decreased memory³⁷, and slower processing speed³⁸. As found by Laberge and Scialfa²¹, age was also related to the amount of time living in Alberta and general familiarity with the province (i.e., subject matter knowledge). The correlation between processing speed and the time needed to complete the visuospatial working memory task emphasized the common time element of both measures. All the memory tests were moderately correlated with the exception of verbal and visuospatial working memory (efficiency), which suggested a common but not redundant memory component. Multicollinearity was observed between reaction times on target absent and target present trials for the processing speed task. To minimize

Table 4. Correlations between predictor variables and measures of web navigation performance in Experiment 1; *a* = Point-biserial correlation; italics: $0.01 < p \leq 0.05$; bold: $p \leq 0.01$; *P*-values for differences between young and old are one-tailed because in most cases the directionality of the relation is known; Memory for website structure is shown as a predictor and performance measure as it has been examined as both during various parts of the statistical analyses; TP = target present; WM = working memory

Variable	Time / trial	Repeat pages / trial	Total pages / trial	Website structure memory
1 Age	0.76	0.03	-0.05	-0.58
2 Gender ^a	0.40	0.08	0.07	-0.22
3 Web Format ^a	0.01	-0.61	-0.56	-0.08
4 Live knowledge	<i>0.27</i>	-0.15	-0.21	-0.29
5 Travel knowledge	-0.14	0.15	0.15	0.15
6 WWW experience	-0.38	0.01	0.05	<i>0.30</i>
7 Verbal WM	-0.44	-0.05	-0.03	0.42
8 Visuospatial WM, time	0.69	0.12	0.07	-0.49
9 Visuospatial WM, efficiency	-0.52	-0.22	-0.21	<i>0.26</i>
10 Processing speed (TP)	0.75	0.08	0.01	-0.50
11 Trial order ^a	0.16	0.24	0.24	0.19
12 Website structure memory	-0.41	0.15	0.22	1.00

redundancy, only reaction time on target present trials was included in subsequent analyses.

Table 4 shows the correlations between the predictors and each performance measure. Increased age was associated with longer times per trial and poorer memory, but there were no age relations for any other measure of performance. Different correlations were observed between the predictors and each performance measure, with time per trial showing the strongest relationship with the majority of the predictors. As expected from the preceding ANOVAs, web format correlated strongly with the number of pages and repeat pages per trial. These relationships were explored further in the regression analyses below.

Hierarchical regression analyses

In order to better understand the age-related differences in time per trial and memory we determined the age-related variance associated with each measure before and after statistically controlling for several important individual difference

variables³⁹. Predictors were included in each regression analysis if they accounted for more than 10% of the variance in the criterion variable, or if the predictor was significantly correlated with age.

Age alone accounted for 57% of the variance in the time per trial ($p < 0.001$). However, age did not significantly add to the prediction of time per trial once working memory and processing speed were controlled, incremental $R^2 = 0.05$, $p = 0.18$. Thus, age differences associated with web navigation speed seem to be tied to general age-related deficits in central processing speed and working memory.

Age alone accounted for 33% of the variance associated with memory for the website hierarchy ($p < 0.001$). As with the regression analysis of time per trial, basic measures of cognitive functioning were able to account for the observed age differences in memory recall such that, once controlled, age was no longer an important predictor of memory, incremental $R^2 = 0.02$, $p = 0.36$.

Discussion of Experiment 1

Overall, age differences were observed in the time taken to find information, but younger and older adults were equally proficient in the other navigation measures. As predicted, age-related variance associated with time per trial and recall was strongly associated with processing speed and working memory.

Participants in the BC-DST condition required fewer pages and repeat pages per trial than in the control condition. Furthermore, the dynamic side-tree was the most frequently used navigation tool in the BC-DST condition. The superior performance seen in the BC-DST format suggests that web developers should incorporate dynamic side-trees into their designs. Because breadcrumbs were rarely used, they do not show as great a potential to improve navigation efficiency as dynamic side-trees. Our findings complement other studies that have found low breadcrumb use compared to other navigation tools such as the back button^{12,20}. Despite low usage, breadcrumbs still offer a number of benefits and have recently shown some growth in their popularity¹⁹.

For younger adults, recall of the website's structure appears to be independent of the available navigation aids. In contrast, older adults had better recall when using the control web format. Perhaps this could be explained by a preference older adults have for simpler hierarchies⁴⁰. This unexpected result may also stem from the higher proportion of pages and repeat pages visited in the control condition. In visiting more pages, users travel the website's hierarchy more often, reinforcing memory for the relationships between the links.

In addition, the two web designs might elicit different navigation strategies. The interface of the control website may impose a reliance on memory that requires more self-initiated or effortful processing because of the low amount of environmental

support. Conversely, the BC-DST condition may foster greater reliance on recognition memory due to the larger amount of environmental support available. In doing so, the reliance on self-initiated processing may weaken, having a negative effect on recall. The aging literature has affirmed that older adults have greater difficulties in recall than in recognition⁴¹⁻⁴³ and that the aged may rely on environmental support more than do younger adults⁴⁴.

A somewhat different explanation is that with demanding tasks such as web navigation, older adults try to alleviate memory demands whenever possible, relying instead on breadcrumbs and dynamic side-trees. Conversely, the control condition may not afford such an opportunity to reduce memory demands. When memory demands cannot be reduced, the resulting increase in rehearsal of the website's hierarchical structure facilitates memory. Evidence of this age-related alleviation of task demands has been found in other domains^{45,46}.

Another possibility is that additional navigation aids may further tax older adult's working memory resources thereby yielding poorer memory for the website's structure. In such a case, we might also expect navigation performance to be worse for older adults in the BC-DST condition or to see our web format manipulation correlate significantly with measures of working memory and/or memory for website structure. Our data do not support this notion. Nevertheless, future research should examine the effects of workload and working memory in relation to navigation aids.

The dynamic side-tree used in Experiment 1 improved performance with respect to efficiency but there was no demonstrable benefit to speed or memory. Knowledge of the website's structure is just one aspect of memory involved in web navigation. The content learned by the web user is equally important. If planning and ex-

ecuting routes through a network of web pages is high in cognitive load, fewer resources will be available for reading, comprehending, and remembering the page content. Experiment 2 was designed to determine if the availability of navigation tools resulted in improvements in content memory and if this might be more so for older adults. Additionally, Experiment 2 examined any practice effects related to the manipulation of web format and age.

EXPERIMENT 2

Method

Participants

A total of 61 paid (\$40 CDN) volunteers participated. Everyone reported good health and had corrected or uncorrected acuity of 20/40 or better at the 50 cm test distance ($M=1.17$ minutes of arc, $SD=0.33$ minutes of arc). Means and standard deviations for participant demographics are shown in Table 1.

Apparatus and materials

Instead of the BC-DST condition as in Experiment 1, we presented the Alberta website with the dynamic side-tree (DST), but no breadcrumbs. All other site characteristics such as content, font size, white space, the layout of text and graphics were unchanged. The control condition was identical to that of Experiment 1. The two web formats can be seen in Figure 1.

WWW experience, subject matter knowledge and visuospatial memory were measured as in Experiment 1. Subject matter knowledge had only one significant principal component accounting for 43% of the variance in all the questions. WWW experience produced two significant components that accounted for 66 % of the variance. The first component reflected participants' current usage of the WWW. The second component reflected general knowledge of WWW and web design. Search speed was estimated with the Trail Making Test, Part B^{47,48}.

Procedure

All participants were tested in two 120 min sessions. In the first session, they completed a demographic questionnaire and a test of visual acuity. Participants then completed the web task using either the control or DST format. Last, we tested intentional recognition memory of the information searched in the website, with 28 questions randomly presented in a multiple-choice format (for instance, "What are the current hours of operation for the Aerospace Museum of Calgary? A: 10 am – 4 pm; B: 10 am – 5 pm; C: 11 am – 4 pm; D: 11 am – 5 pm"). The second session was identical to the first but forwent the demographic questionnaire and acuity test and instead included a measure of visual search and visuospatial working memory. In total, there were 2 practice and 80 randomly presented experimental trials (40 trials per session).

Results of Experiment 2

Age x web format x practice analyses of variance

Table 5 gives the means and standard deviations for the performance measures. For time per trial, the main effect of web format was not significant, $p=0.29$; $\eta_p^2=0.02$. There was a main effect of Practice $p<0.001$; $\eta_p^2=0.70$. The main effect of age was also found to be significant, $p<0.001$; $\eta_p^2=0.47$. On average, younger adults ($M=23.12$, $SD=4.72$) finished trials faster than older adults ($M=36.44$, $SD=9.66$). There was also a significant age x practice interaction ($p=0.002$; $\eta_p^2=0.15$), because older adults improved more than their younger counterparts. The remaining higher-order interactions were nonsignificant ($ps\geq 0.66$; $\eta_p^2s\leq 0.004$).

For the total number of pages visited, there was no main effect for age, $p=0.39$; $\eta_p^2=0.01$. There was a significant effect of Practice, $p<0.001$; $\eta_p^2=0.50$. In general, participants reduced the number of pages per trial from session 1 ($M=5.39$, $SD=1.18$) to session 2 ($M=4.54$, $SD=0.77$). Contrary

to our predictions, the web format effect was not significant, $p=0.10$; $\eta_p^2=0.05$. The remaining higher-order interactions were also nonsignificant ($ps \geq 0.10$; $\eta_p^2s \leq 0.05$).

On the number of repeat pages per trial, there was no main effect for age, $p=0.66$; $\eta_p^2=0.01$. A Practice effect was observed, $p<0.001$; $\eta_p^2=0.59$. In general, participants reduced the number of repeat pages per trial from session 1 ($M=3.37$, $SD=1.05$) to session 2 ($M=2.49$, $SD=0.69$). Contrary to our predictions, the web format effect was not significant, $p=0.11$; $\eta_p^2=0.04$. The higher-order interactions were also nonsignificant ($ps \geq 0.09$; $\eta_p^2s \leq 0.05$).

The results of a three-way ANOVA on recognition memory for content revealed only a significant main effect of age, $p<0.001$; $\eta_p^2=0.20$. As expected younger individuals, in general, had better recognition memory ($M=74.83$, $SD=9.57$) than older individuals ($M=67.40$, $SD=10.06$). The remaining main effects ($ps \geq 0.10$; $\eta_p^2s \leq 0.05$) and higher-order interactions ($ps \geq 0.16$; $\eta_p^2s \leq 0.03$) were nonsignificant.

Proportion of navigation methods used

The percent of navigation tools used by younger and older adults for the two web formats was also examined. An age x web

format ANOVA revealed no significant interaction for the navigation methods used ($ps \geq 0.08$; $\eta_p^2s \leq 0.05$). Age differences were significant only for menu clicks, $p=0.04$; $\eta_p^2=0.07$. Older adults (41.4%) appear to use the menu (either static side-bar menu or dynamic side-tree) slightly more often than their younger counterparts (36.6%). All other age effects were nonsignificant ($ps \geq 0.07$; $\eta_p^2s \leq 0.06$).

Web format effects were observed for the back button, (control=13.4%, DST=9.6%; $p=0.04$; $\eta_p^2=0.07$), menu (control=26.1%, DST=51.1%; $p<0.001$; $\eta_p^2=0.62$), and in-page clicks (control=62.3%, DST=39.9%; $p<0.001$; $\eta_p^2=0.64$). The back button was used more often by participants in the control condition (13.4%) than by those in the DST condition (9.7%). Participants in the DST condition relied more on the dynamic side-tree (51.1%) while those in the control relied more on in-page links (62.3%). Remaining web format effects were nonsignificant ($ps \geq 0.15$; $\eta_p^2s \leq 0.04$).

Correlations among variables

The intercorrelations among predictors are shown in Table 6. As expected, increased age was associated with less WWW experience, decreased memory, and longer search times. Age was positively related

Table 5. Means and standard deviations (SD) for performance measures in Experiment 2; DST = dynamic side-tree condition

Variable	Younger persons				Older persons			
	Control (n=16)		DST (n=15)		Control (n=15)		DST (n=15)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Session 1								
Time / trial	25.02	5.81	26.56	4.77	39.67	13.09	42.60	10.49
Repeat pages / trial	3.72	1.08	3.09	0.96	3.27	0.88	3.38	1.24
Total pages / trial	5.92	1.40	5.12	1.01	5.20	0.89	5.30	1.28
Content memory	75.51	9.63	73.57	8.83	66.35	11.59	65.71	12.13
Session 2								
Time / trial	20.06	4.35	20.90	4.01	30.32	7.35	33.16	7.76
Repeat pages / trial	2.89	0.79	2.17	0.58	2.47	0.62	2.40	0.60
Total pages / trial	4.94	0.89	4.25	0.71	4.52	0.71	4.43	0.63
Content memory	80.08	7.39	69.76	9.81	68.98	8.97	68.57	8.23

to knowledge of Alberta. The correlation between Trails B and the time needed to complete the visuospatial working memory task emphasized the common speed element of both measures. All the memory tests were moderately correlated, which suggested a common memory component.

Table 7 shows the correlations between the predictors and each performance measure. Increased age was associated with longer times per trial and poorer recognition memory for content. Time per trial showed the strongest relationship with the majority of the predictors, indicative of the common speed element in our variables. Visuospatial working memory and search speed (Trails B) both showed a significant relationship with time per trial and recognition.

Hierarchical regression analyses

To further examine the age-related differences in time per trial and memory for content, regression analyses were conducted in a similar manner to that of Experiment 1.

For session one, age alone accounted for 41% of the variance in the time per trial ($p < 0.001$). Once visuospatial working memory, memory for content, search speed, and web experience were controlled, age still accounted for a marginally significant portion of the variance in time per trial, $R^2 = 0.06$, $p = 0.08$.

Similarly for session two, age alone accounted for 44% of the variance in the time per trial ($p < 0.001$). Again, once visuospatial working memory, memory for content, search speed, and web experience were controlled, age still accounted for a significant portion of the variance in time per trial, $R^2 = 0.10$, $p = 0.02$.

In session one, age alone accounted for 12% of the variance associated with recognition memory for content ($p = 0.006$). Once visuospatial working memory was controlled, the observed age differences in memory for content were eliminated, $R^2 = 0.01$, $p = 0.50$. Similarly, age did not significantly add to the prediction of recognition memory for content once either search speed, $R^2 = 0.02$, $p = 0.30$, or web experience was controlled, $R^2 = 0.03$, $p = 0.18$.

Table 6. Correlation matrix for predictor variables in Experiment 2; *a* = Point-biserial correlation; italics: $0.01 < p \leq 0.05$; bold: $p \leq 0.01$; *P*-values for differences between young and old are one-tailed because in most cases the directionality of the relation is known; WM = working memory; (1) and (2) denote sessions

Variable	Variable											
	1	2	3	4	5	6	7	8	9	10	11	
1 Age	-											
2 Gender ^a	-.16	-										
3 Web Format ^a	-.02	-.05	-									
4 Years of Education	.14	.05	.03	-								
5 Alberta Knowledge	.54	-.17	-.13	.07	-							
6 WWW usage	-.68	.11	.24	.08	-.49	-						
7 WWW expertise	.24	-.05	.03	.25	-.01	.00	-					
8 Trails B, time	.52	-.25	.02	-.15	.24	-.39	.13	-				
9 Visuospatial WM, time	.71	-.18	-.02	-.09	.46	-.69	.11	.67	-			
10 Visuospatial WM, efficiency	-.36	-.07	.05	.02	-.18	.40	-.25	-.42	-.70	-		
11 Content memory (1)	-.35	.06	.06	.30	.04	.28	-.19	-.47	-.45	.40	-	
12 Content memory (2)	-.27	.17	.29	-.01	-.06	.25	-.32	-.28	-.28	.33	.36	-

Age and navigation aids

Table 7. Correlations between predictor variables and measures of web navigation performance in Experiment 2; *a* = Point-biserial correlation; italics: $0.01 < p \leq 0.05$; bold: $p \leq 0.01$; *P*-values are one-tailed because in most cases the directionality of the relation is known; Memory for content is shown as a predictor and performance measure as it has been examined as both during various parts of the statistical analyses; WM = working memory; (1) and (2) denote sessions

Variable	Session 1				Session 2			
	Time/ trial	Repeat pages/ trial	Total pages/ trial	Content memory	Time/ trial	Repeat pages/ trial	Total pages/ trial	Content memory
1 Age	.64	-.04	-.11	-.35	.67	-.09	-.10	-.27
2 Gender ^a	-.10	.11	.17	.06	-.10	.04	.04	.17
3 Web format ^a	-.10	.13	.15	.06	-.12	.29	.26	.29
4 Knowledge of Alberta	.28	-.22	-.28	.04	.28	-.36	-.38	-.06
5 WWW usage	-.54	.12	.23	.28	-.56	.28	.27	.25
6 WWW expertise	.11	.16	.13	-.19	.08	.19	.18	-.32
7 Trails B, time	.64	.14	.08	-.47	.60	.12	.12	-.28
8 Visuospatial WM, time	.69	-.04	-.12	-.45	.66	-.09	-.09	-.28
9 Visuospatial WM, efficiency	-.46	-.10	-.05	.40	-.42	-.08	-.07	.33
10 Content memory (1)	-.53	-.17	-.14	1.00	-.54	-.21	-.23	.36
11 Content memory (2)	-.20	-.05	-.03	.36	-.22	-.09	-.09	1.00

In session two, age alone accounted for 8% of the variance associated with recognition memory for content ($p=0.03$). Once visuospatial working memory was controlled, the observed age differences in memory for content were eliminated, $R^2=0.03$, $p=0.18$. Similarly, age did not significantly add to the prediction of recognition memory for content once search speed, $R^2=0.02$, $p=0.23$, or web experience was controlled, $R^2=0.002$, $p=0.74$. Thus, the relatively small age differences in recognition memory can be accounted for by any of a number of basic processes including familiarity and working memory.

Discussion of Experiment 2

Overall, findings from Experiment 1 and 2 are quite similar. Experiment 2 demonstrated age differences in search time and recognition memory of the information searched. Again, younger and older adults appear to be equally proficient in other aspects of performance.

Improvements were observed in all aspects of performance with the exception of recognition memory for content. The exception may be explained by the fact

that it was an intentional memory task and so performance may already be at peak levels for the first session.

GENERAL DISCUSSION

Aging and WWW search

The current study examined the influence of age and web design on the task of WWW navigation. Overall, age differences were observed in the time taken to find information, the recall of the website's organization, and the later recognition of that information. As predicted, age-related variance associated with time per trial and recall of web organization was associated with processing speed and working memory. Contrary to the assertion that older adults are more prone to disorientation in the WWW, there was no age effect on total pages or repeat pages visited. As well, older adults' navigation benefited from the inclusion of the dynamic side-tree as much as younger adults (Experiment 1) and they used it in search at least as much as the young (Experiments 1 and 2).

Our findings are consistent with gerontological research on computer usage. For example, Westerman et al.⁴⁹ showed that

older adults were slower in retrieving information from a computer database, but observed no differences in accuracy or efficiency. Our findings also mirror those of Laberge and Scialfa²¹, wherein age-related differences were observed in the time to locate information on a website, but not in the number of pages or repeat pages visited. Results suggest that older adults might sacrifice their speed to maintain accuracy (but see Mead et al.²⁸). An alternate explanation is that older adults are efficient in web navigation; they are simply slower than younger adults.

Also in agreement with past research, the current study has shown that measures of processing speed and working memory act as mediators of age-related differences in time-based navigation performance. Our results mirror other cognitive aging research^{43,44} on episodic memory, in that older adults had difficulty recalling the web site's structure (Experiment 1) and recognizing web site content (Experiment 2). Against expectations, in Experiment 1 for older adults the BC-DST format yielded lower memory scores than the control format. This may stem from a preference among older adults for simpler hierarchies⁴⁰, the less efficient navigation in the control format resulting in more rehearsal of the website's hierarchy, or older adults' reliance on environmental support afforded by the BC-DST/DST conditions⁴²⁻⁴⁴

The effects of navigation aids

In Experiment 1, participants in the BC-DST condition did not produce faster search times despite requiring fewer pages and repeat pages per trial than the control condition. Furthermore, the dynamic side-tree was the most frequently used navigation tool in the BC-DST condition. Experiment 2 did not yield significant benefits for the DST condition. Although this may contradict the notion that side-trees are an effective navigational aid, it is important to look at the differences in the two methodologies. The navigation trials in Experiment

1 were grouped into related categories, but this was not the case in Experiment 2. Because the dynamic side-tree reveals more links in the web site, more efficient paths between related points are visible to the user which benefits users when searching within categories. In contrast, when questions are randomly ordered (Experiment 2), this is not necessarily the case. To the extent that people search through related categories, the dynamic side-tree will afford greater efficiency.

One of the major purposes of this study was to determine if the presence of navigation aids resulted in improved memory for either the structure (Experiment 1) or content (Experiment 2) of a website. We predicted that dynamic side-trees would free working memory and allow the allocation of cognitive resources to other task components. This did not occur. In fact, older adults (Experiment 1) and younger adults (Experiment 2) demonstrated better memory when navigation was not aided by the side-trees. There are at least two possible reasons for lack of a consistent format effect. One is that people are cognitive misers and that, when given a tool that allows them to navigate more easily, they do not re-allocate resources to memory. Certainly this would be understandable because there was no strong intrinsic motivation to learn about the web site. The other possibility is that our participants were so familiar with the WWW that the provision of dynamic side-trees did not add significantly to their ability to search the site. If this is the case, then a more naïve group of users would show greater benefits from navigation aids.

Limitations

One methodological issue in Experiment 1 is that we only tested two navigation aid conditions; a BC-DST format with both navigational aids and a control format without them. One could easily argue for the separation of breadcrumbs and the dynamic side-tree. In fact, pilot data

found that breadcrumbs were never used by any of the participants exposed to the breadcrumb only or BC-DST conditions. The low breadcrumb usage in the current study agrees with those pilot data. Importantly, one should not dismiss the usefulness of breadcrumbs entirely. Individuals may use breadcrumbs as a visual aid to orient themselves within a website. Future eye-tracking studies may lend support to this idea. As mentioned earlier, breadcrumbs are growing in popularity as their benefits are becoming known to users¹⁹.

A second methodological detail worth mentioning is the way in which we measured recall for the website's hierarchy (Experiment 1). Participants were given an example of a hierarchical tree-like structure and then asked to recall the entire structure of the website (approximately 420 pages). Such a task may not reflect what one needs to know about a website for effective use. For example, when one revisits a website to check the local city weather, one would not need to recall how to select the desired city if a link to the city was visible. Perhaps users just need to recognize 'where to go' rather than recall the website structure. If this is the case, then a recognition test would be more meaningful.

Our results were obtained in homogeneous, healthy, web-experienced, and highly functioning groups of younger and older individuals. Presumably, age differences found in performance would be greater in more heterogeneous samples. It is also conceivable that with more naïve users, web format effects would be much larger. This is because way-finding tools are of greatest importance for those who are unfamiliar with an environment, physical or virtual.

Website design and usability

Findings from the current study suggest that cognitive factors, including working memory and processing speed, are linked

to web navigation performance. One implication is that, when possible, web designers need to reduce the cognitive demands required for navigation. In doing so, performance will improve, especially for the growing elderly population who are often characterized by cognitive declines. Exactly how designers can accomplish this is still open to debate. Present suggestions include simplified interfaces⁵⁰, better training⁵⁰, and better organized layouts^{50,51}. As well, future research should examine which methods improve performance by easing demands on working memory and processing speed. We have shown that cognitive demands are linked to speed-based performance measures. By finding ways to reduce these demands during navigation, it is possible to save time in searching.

It is also important to consider which aspects of performance are most critical when designing a website. If the memory of the website's structure is an important attribute for future visits, keep in mind that older adults have decreased memory abilities. To help older adults, considerations include adopting more simplistic designs to ease learning of the hierarchical structure of the website. Additionally, designers can make the site structure explicit and obvious, for example, by using site maps as advance organizers. Again, website owners who see time as an important performance measure should focus on reducing demands on working memory and processing speed to assist older adults. Finally, if reducing direct indicators of disorientation is a primary goal, consider implementing dynamic side-trees into the design.

There are, however, risks associated with the addition of navigational aids, such as increased complexity and clutter of the interface. Furthermore, users with varying degrees of web expertise may use the same site, and so navigation aids may help some individuals while hindering oth-

ers. One could allow navigation aids to be made available at the user's discretion. Also, research from Resnick and Sanchez argues for creating better organization and applying user-centered labels to render navigation menus and other components more accessible⁵¹.

FUTURE DIRECTIONS

There is a great deal of research to be done in the area of aging and web navigation. Other measures such as user satisfaction and perceived level of disorientation should be considered. Future research can explore such variables using qualitative approaches like usability testing, surveys,

and focus groups. As mentioned, the current study examined groups of users who knew both the domain and the WWW. Future work should also examine naïve users who are less knowledgeable about the domain and less experienced with the medium. It is possible that naïve users show larger benefits from navigation aids than their more experienced counterparts. Additionally, individuals with cognitive impairments may also show greater benefits from navigation aids. Thus, by extending the current study to more diverse groups we can further our understanding of web design and ameliorate poor navigation performance.

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