Designing an Information Search Interface for Younger and Older Adults

Richard Pak and **Margaux M. Price,** Clemson University, Clemson, South Carolina

Objective: The present study examined Web-based information retrieval as a function of age for two information organization schemes: hierarchical organization and one organized around tags or keywords. **Background:** Older adults' performance in information retrieval tasks has traditionally been lower compared with younger adults'. The current study examined the degree to which information organization moderated age-related performance differences on an information retrieval task. The theory of fluid and crystallized intelligence may provide insight into different kinds of information architectures that may reduce age-related differences in computer-based information retrieval performance. **Method:** Fifty younger (18–23 years of age) and 50 older (55–76 years of age) participants browsed a Web site for answers to specific questions. Half of the participants browsed the hierarchically organized system (taxonomy), which maintained a one-to-one relationship between menu link and page, whereas the other half browsed the tag-based interface, with a many-to-one relationship between menu and page. This difference was expected to interact with age-related differences in fluid and crystallized intelligence. **Results:** Age-related differences in information retrieval performance persisted; however, a tag-based retrieval interface reduced age-related differences, as compared with a taxonomical interface. **Conclusion:** Cognitive aging theory can lead to interface interventions that reduce age-related differences in performance with technology. In an information retrieval paradigm, older adults may be able to leverage their increased crystallized intelligence to offset fluid intelligence declines in a computer-based information search task. **Application:** More research is necessary, but the results suggest that information retrieval interfaces organized around keywords may reduce age-related differences in performance.

INTRODUCTION

Adults are increasingly using the Internet as a primary source of news, information, and access to services (Pew Internet & American Life Project, 2006). However, older adults are still less likely to report Internet usage (Pew Internet & American Life Project, 2005) than are other age groups, and they report more difficulties (Chadwick-Dias, McNulty, & Tullis, 2003; Redish & Chisnell, 2004). Given the large body of literature that has documented the age-related changes in cognition (e.g., Craik & Salthouse, 2000; Hawthorn, 2000), the primary research question was whether an information search interface could be designed to specifically accommodate age-related cognitive changes.

A broad way to organize age-related changes in cognition is in terms of fluid and crystallized intelligence (e.g., Horn & Cattell, 1967). Fluid intelligence refers to those abilities that allow individuals to think and act in novel situations (e.g., reasoning ability) and are thought to be unbiased by educational level or experience (Garfein, Schaie, & Willis, 1988). Example indicators of fluid intelligence are working memory and spatial abilities. Crystallized intelligence can be described as the products of experience or education. Indicators of crystallized intelligence are tests of general knowledge or vocabulary. It has been well established that fluid intelligence generally shows significant age-related declines, whereas crystallized intelligence remains stable or increases with age (e.g., Horn, 1982; Horn & Cattell, 1967; Kausler, 1991; Schaie, 1996).

Address correspondence to Richard Pak, Department of Psychology, Clemson University, Clemson, SC 29634; richpak@clemson.edu. ***HUMAN FACTORS,*** Vol. 50, No. 4, August 2008, pp. 614–628. DOI 10.1518/001872008X312314.

Accommodating Age-Related Changes in Cognition

In this study, we examined the possibility that a computer-based task could be redesigned to specifically place more demand on crystallized abilities and reduce demands on fluid abilities. Most information search tasks examined in previous studies (e.g., Pak, Rogers, & Fisk, 2006; Vicente, Hayes, & Williges, 1987) utilized hierarchically organized systems. Prior research has shown that navigating hierarchical menu systems places demands on spatial ability (Chen & Rada, 1996; Laberge & Scialfa, 2005; Pak et al., 2006; Seagull & Walker, 1992; Stanney & Salvendy, 1995; Vicente & Williges, 1988; Vicente et al., 1987; Westerman, 1997). The observed relationship between spatial abilities and performance may be induced by the need for the user to create and utilize a system representation to guide action (Ehrlich, 1996). In a hierarchical system, a Web page on the topic of oranges might be located in the following hierarchical structure:

1. Fruit
    a. Melons
    b. Citrus
        i. Orange
        ii. Lemon
2. Vegetables

The page "orange" is located under the category of "citrus," which is located in the superordinate category "fruit." To find the "orange" page, users must first identify the fruit category and subsequently drill down until they reach the desired page. Each page or document has a unique "location" within the system – that is, unless the "orange" page is deliberately duplicated into another category, it can be found only in that initial unique location (Weinberger, 2007). This one-to-one relationship between menu or link and page requires that the user know precisely the correct link before he or she can reach the desired page. Another example of a hierarchical system may be the way in which some people organize files on their computer, with folders within folders.

In comparison, information in tag-based systems is assigned tags (keywords) to organize it instead of being placed into hierarchically related categories. Some tag-inspired systems do not incorporate strong hierarchical relationships between descriptors or categories. Additionally, tag systems allow a single piece of information (e.g., a Web page) to be assigned any number of descriptors, unlike the unique-location requirement of taxonomies.

Using the previous example, the "orange" page might be assigned the descriptive tags *fruit, citrus,* and *round.* To find the "orange" page, the user would see a list of tags and could click on any of them to reach the desired page. Browsing through such tags may not involve moving through a hierarchy or keeping track of higher-level categories (and presumably will not require the creation and manipulation of a mental model and, consequently, will rely less on spatial abilities). This many-to-one relationship between menu and page may facilitate performance by relying on the individual's ability to generate synonyms of desired concepts – a vocabulary-demanding task.

It should be noted that although the tag-based systems appear to be hierarchical menus (albeit broad and shallow), tag retrieval interfaces differ in a more fundamental way from hierarchical menus. A menu with broad breadth and little depth still has the hierarchical menu limitation of an item being in a single location (the page labeled "orange" can exist only in a single category or folder). Although files can be duplicated and placed into different categories, this may cause problems with synchronization as one file gets updated and the other does not (Weinberger, 2007). Thus in a taxonomy, the user must find the proper unique category to reach the desired page. Tag-based systems explicitly allow information to have multiple keywords, resulting in an increased probability that a particular keyword generated by the user (e.g., *fruit*) is linked to the desired information. Because of older adults' greater vocabulary, they may be more able to generate proper keywords than are younger adults.

Tag-based interfaces have a comparatively flat organizational structure as compared with taxonomical interfaces. In addition, within a tag-based interface, there is a many-to-one relationship between menu item (e.g., hyperlink) and page. That is, pages within a Web site can be accessed from many different tags. This is contrasted with information in a taxonomical system, in which the relationship between menu item and page is one to one or pages may be accessed only if the user selects the one correct menu option. Tag-based interfaces may place fewer demands on spatial abilities (because of the reduced need to "know where you are" in the system) while simultaneously increasing vocabulary demands because of the reliance on the ability to generate keywords.

In an attempt to more clearly define the differences between the two types of information retrieval systems, we previously conducted a task analysis of information retrieval under a taxonomy and tag-based system (Figure 1; Pak, Pautz, & Iden, 2007).

In a taxonomy (hierarchically organized system), when a user wishes to retrieve a Web page, he or she starts by having a general conception of the type of information desired (e.g., cruise information; Figure 1a, Steps 1.0 and 1.1). Next, the user will have to identify the appropriate top-level category or folder and, once that is selected, will subsequently "drill down" to more specific categories contained within the main category until the items within the category are reached (Steps 1.2 and 1.3). Finally, the user can then select the appropriate Web page. The iterative steps of 1.2 and 1.3 are hypothesized to be benefited by having a good mental representation of the information organization and thus be enhanced by good spatial abilities.

In a tag-based system, as in the taxonomy system, the user must convert his or her general conception of the desired information into explicit keywords to click (Figure 1b). However, in the tag-based system, the user's ability to *generate* and recognize keywords or synonyms of the desired concept may play a larger role in performance (Steps 1.2 and 1.3). In addition, because of the many-to-one mapping between menu option and page, the user's chance of generating a correct keyword is increased, as compared with that in a taxonomy (in which the user must correctly select the one category). We expect that because navigation in the tag-based condition is dictated primarily by the meaning of the term and less by the location of the item, users with a high vocabulary (i.e., older adults) would be better at the subtask of formulating these descriptors – and recognizing any synonyms presented in the interface – when compared with users who have a lower vocabulary (i.e., younger adults).

The goal of the current study was to compare younger and older adults' performance between two information organization interfaces: taxonomy and tag-based. The current study examined whether age-related performance differences on an information search task could be reduced by increasing the vocabulary requirements (an indicator of general knowledge) and decreasing the spatial ability requirements. Placing greater demand on vocabulary while simultaneously reducing demand on age-declining spatial abilities is expected to result in improved information retrieval performance for older adults (as compared with a taxonomically organized system).

The tag-based system was based on cognitive aging research and our prior analyses of information search interfaces that suggested that older adults' performance would improve with an interface that reduced demands on spatial abilities and increased demands on vocabulary. Vocabulary demands were increased and spatial ability demands decreased by eliminating hierarchical organization (taxonomies) in favor of a flat, keyword-based structure reminiscent of tag-based systems common to many Web-based applications (Web sites such as http://flickr.com, http://del.icio.us, and http://gmail.com).

METHOD

Participants

Fifty younger adults (23 men and 27 women) ranging in age from 18 to 23 years (M = 19.92, SD = 1.38) and 50 older adults (23 men and 27 women) ranging in age from 55 to 78 years (M = 67.39, SD = 5.31) completed the study. The younger adults were undergraduate college students, whereas the older participants were independently living, community-dwelling older adults. All participants reported some computer experience, with younger adults reporting a mean computer experience level of 4.90 (SD = 0.51, on a scale of 1–5 with 1 indicating *less than 6 months of experience* and 5 indicating *at least 5 years of experience*). The mean computer experience level for older adults was 4.56 (SD = 1.16). The younger participants chose to receive either course credit or $7/hr, whereas the older participants received $7/hr.

Materials

Ability measures. The following abilities were assessed: perceptual speed (digit-symbol substitution; Wechsler, 1997), memory span (reverse digit span; Wechsler, 1997), spatial orientation (cube comparison; Ekstrom, French, Harman, & Dermen, 1976), spatial visualization (paper-folding; Ekstrom et al., 1976), and vocabulary (Shipley vocabulary; Shipley, 1986). A shortened computer

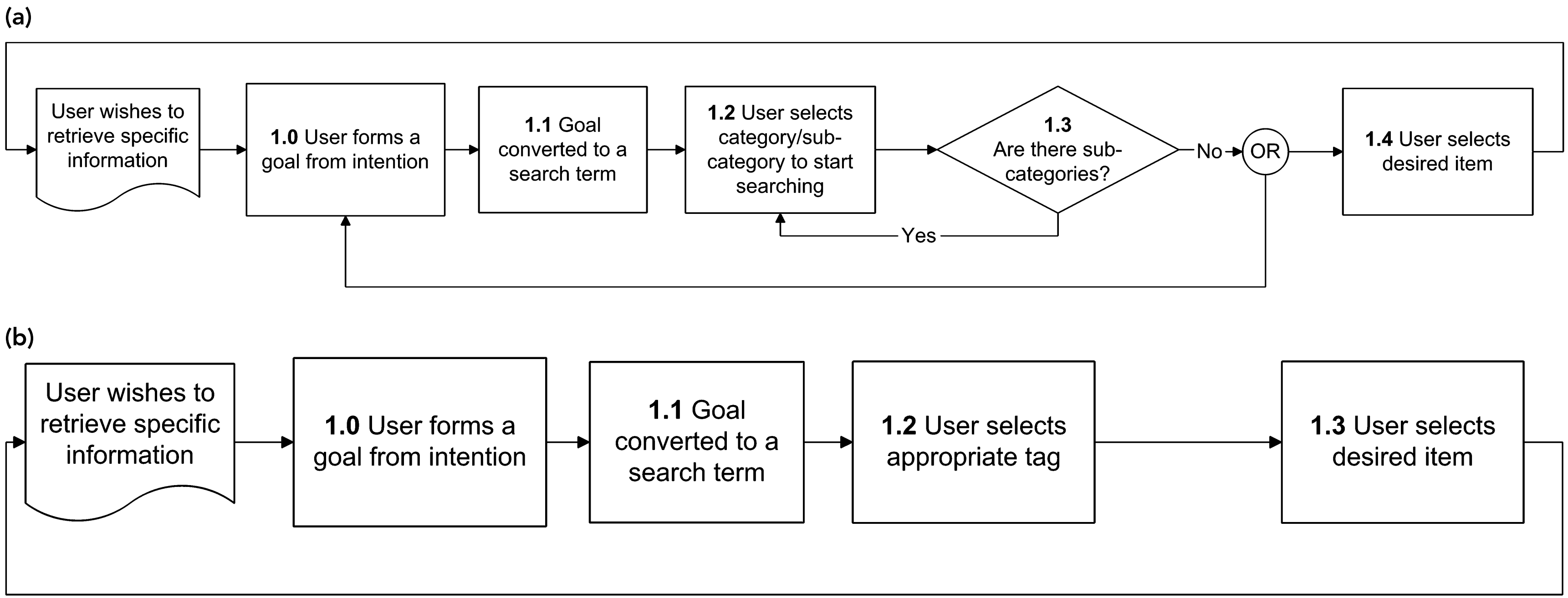


Figure 1. Hypothesized cognitive processes involved in navigating (a) a hierarchical taxonomy system and (b) a tag-based system. Adapted from Pak, Pautz & Iden. (2007). *Cognitive Technology, 12,* 31–44, with permission.

experience questionnaire was also administered (Czaja, Charness, Fisk, Rogers, & Sharit, 2001). The specific measures were chosen because they are commonly used, reliable indicators of their respective abilities (e.g., Czaja et al., 2006). General participant characteristics are provided in Table 1.

Equipment. PC-compatible computers running at 3.2 GHz with 2 GB of RAM were used with a 19-inch (48.3-cm) LCD monitor set at a resolution of 1280 × 1024 pixels. Participants were seated approximately 18 inches (45.7 cm) from the monitor.

Information retrieval Web site. Ninety-six Web pages were gathered from various sources of general travel information on the Web. The information was standardized so that length, text size, and general type of content were consistent across all pages. The travel domain was chosen because we wanted a domain in which there might be smaller age differences in level of knowledge (Pak, Mayhorn, Stronge, & Padgett, 2002).

The Web pages were organized into a taxonomic or tag-based system. The essential difference in how these two conditions organize information is illustrated in Table 2, and the user's experience in Figure 2. In the taxonomic condition, Web pages were organized in a manner in which related pages were placed into similar groups to simulate how information is organized in common information retrieval applications. In addition, groups of pages could be inside higher-order groups (e.g., a group of pages on obtaining passports could be under the "forms" category, which itself was under the "travel documents" category).

The organization was obtained by performing four independent card sorts of 96 pages and merging the results. The card sorters were undergraduate students and were unaware of the study purpose. They were told to organize the pages into the most logical groups or "folders" and that folders could contain other folders if necessary. The USort application was used to carry out the card-sorting activity, and EZCalc application was used in the subsequent analysis (Dong, Martin, & Waldo, 2001). The card sorting led to the creation of six main categories (air travel, cruise travel, general travel tops, health and safety, passports, and train travel), each with a varying number of subcategories (see Figure 2a).

For the tag-based condition, tags were derived from the taxonomic organization of pages by converting hierarchically organized pages into those organized around tags. Tags were generated by converting the terms used within the taxonomic organization such that each Web page was assigned one tag for each level of the hierarchical path in which it resided (e.g., a Web page located in the "Air Travel/Safety/Airport Security" path was assigned the three tags "Air Travel," "Safety," and "Airport Security"). The creation of tags in this condition was not user generated (sometimes known as "free tagging") but experimenter generated. This method of tag creation was done to control for the type of tags given to each participant and to equalize the type and content of information presented between our two conditions (i.e., so that more descriptive information would not inadvertently be presented in one condition than in the other).

The main difference between the two conditions was that in the taxonomy condition, Web pages were accessible only if the participant reached the single category in which it resided (e.g., in Figure 2a the "Luggage" page resided only in the "Packing" category). However, in the tag-based condition, Web pages could be accessed by selecting any tag that was associated with the page (e.g., in Figure 2b the "Luggage" page was tagged with "Cruise travel," "Packing," and "Before you Leave").

The final experimental Web sites contained 96 pages organized hierarchically (taxonomy) or by using keyword labels (tag based). Because the same label terms were used across both interfaces, the only difference between the two conditions should be the nature of the organization scheme and access interface. The Web site was presented using the Firefox Web browser in full-screen mode with all tool, status, and menus bars turned off (Figure 2). The only navigational tools available were a back button and a home button (in addition to the navigation afforded by the links, represented in blue on the site). The resolution of the display permitted viewing of the screen without vertical scrolling.

Task. There were 2 practice tasks and 30 experimental tasks. For each trial (randomly presented) the participant's task was to retrieve specific information by browsing the Web site. Participants browsed using the navigational interface on the left side (tag-based or taxonomy interface) by clicking on the blue category labels or tags. Clicking on a category or tag displayed all of the individual Web pages that were in that category (taxonomy condition) or labeled with that tag (tag-based condition). Once the answer was identified, participants

TABLE 1: Descriptive Statistics on Ability Indicators and Performance by Condition and Age Group

	Taxonomy						Tag Based					
	Young (N = 25)			Old (N = 25)			Young (N = 25)			Old (N = 25)		
	Mean	*SD*	Range	Mean	*SD*	Range	Mean	*SD*	Range	Mean	*SD*	Range
Age	19.68	1.44	18 to 23	67.60	5.41	55 to 78	20.16	1.31	18 to 23	67.60	5.32	59 to 77
Computer experience[a]	5.00	0.00	5 to 5	4.60	1.15	1 to 5	4.80	0.71	2 to 5	4.52	1.19	1 to 5
Perceptual speed*[b]	65.80	10.41	50 to 93	53.96	7.51	42 to 70	62.80	16.79	37 to 100	54.92	10.80	35 to 77
Memory span*[c]	9.56	2.18	6 to 14	8.32	2.39	5 to 14	9.48	2.97	2 to 14	8.52	2.18	3 to 12
Spatial visualization*[d]	5.70	1.38	3 to 8	3.72	1.52	1 to 7	6.20	1.68	4 to 10	3.92	1.82	1 to 8
Spatial orientation*[e]	12.08	3.49	5 to 18	9.42	2.73	4 to 17	11.14	4.13	3 to 19	9.12	3.00	3 to 15
Vocabulary*[f]	30.20	4.19	20 to 39	34.64	3.19	29 to 39	31.60	3.01	26 to 36	35.00	2.55	29 to 38
Task completion time (s)	37.67	10.88	15 to 69	70.88	22.81	42 to 127	43.55	13.05	24 to 82	65.61	22.23	33 to 124
Number of mouse clicks	5.67	1.07	4 to 9	6.06	1.35	4 to 11	5.88	1.77	4 to 11	5.04	1.51	3 to 10
Number of errors	0.32	0.31	0 to1	0.62	0.42	0 to 2	0.69	0.73	0 to 3	0.51	0.66	0 to 3
Composite performance	–0.37	0.48	–1.2 to 1.4	0.38	0.73	–0.8 to 2.7	–0.02	0.94	–1.1 to 2.5	0.01	0.94	–1.1 to 2.8

[a]Total length of computer experience on a scale of 1 (*less than 6 months*) to 5 (*greater than 5 years*). [b]Digit symbol substitution (number correct; Wechsler, 1997). [c]Reverse digit span (Wechsler, 1997). [d]Paper folding test (Ekstrom et al., 1976). [e]Cube comparison test (Ekstrom et al., 1976). [f]Shipley vocabulary test (Shipley, 1986). For all ability measures, higher values indicate better performance. For the performance measures, lower values indicate better performance.

*Indicates significant age group difference at $p < .05$. (There were no significant Age × Condition interactions in any of the participant abilities.)

TABLE 2: Description of the Taxonomy and Tag-Based Conditions

Condition	Example	Description
Taxonomy	Health & Safety → Before you leave → Vaccinations → **Influenza Vaccine**	The desired page, Influenza Vaccine, is located in a single location: within the vaccinations subcategory. The page is not accessible from any of the higher-level categories (just as a document placed in a subfolder is not directly accessible from a higher-level folder).
Tag based	Vaccinations → **Influenza Vaccine**; Before you leave → **Influenza Vaccine**; Health & Safety → **Influenza Vaccine**	The desired page, Influenza Vaccine, was labeled with three different tags ("Vaccinations," "Before you Leave," and "Health & Safety"), so clicking on any of these labels will display the Influenza Vaccine page.

clicked on the answer on the Web page to end the trial.

For example, to retrieve information in response to "find the address to mail a passport application," the participant would browse through the hierarchical categories (for taxonomy) or tags (for the tag-based scenario) until finding the Web page that contained the mailing address. Once the appropriate Web page was found, the participant clicked on the mailing address to end the trial. The participants then received feedback, which was followed by the next task. Each information-retrieval task had a specific answer that was found on exactly one Web page, and no Web page contained answers for more than one task. There was no visual feedback or indication to identify the clickable areas that represented the answers (i.e., no blue underlined text or "finger" mouse pointers).

The Web application (programmed in the PHP scripting language) ran on a local Apache-based Web server and logged the name of the visited page, the time spent on each page (in seconds), and the number of times the back or home button was clicked. Clicking the back or home button was considered an error because it indicated that the participant mistakenly selected a page (requiring the back button) or gave up and needed to start the task over (home).

Design and Procedure

The study was a 2 (age group: young, old) × 2 (information organization condition: taxonomy or tag based) factorial with age group as a grouping variable and information organization as a between-groups variable. Participants were randomly assigned to each condition. The dependent variables were task completion time (in seconds), number of mouse clicks made, and errors per task.

Participants (in groups of 2 to 4 people) completed the ability tests. After a short break, participants started the information retrieval tasks. Participants were first given a verbal description of the task and guided in the completion of an example task at the computer (all responses made with the mouse in the preferred hand). During the guided example, the participants were familiarized with the major elements of the screen (e.g., the task area, the navigation buttons, use of the mouse). Participants then completed a second example on their own, after which they were told to complete the 30 experimental tasks quickly but as accurately as possible. These instructions were reiterated at the start of every task by the computer.

RESULTS

Descriptive statistics for the ability and performance measures by age group and condition are in Table 1. A one-way ANOVA showed significant age group differences on abilities, such that the younger adults had faster perceptual speed, $F(1, 99) = 17.46$, $p < .05$, larger memory span, $F(1, 99) = 30.25$, $p < .05$, and higher spatial visualization and orientation abilities, $F(1, 99) = 43.93$, $p < .05$, and $F(1, 99) = 12.11$, $p < .05$, respectively, than older adults. However, older adults scored higher on the vocabulary test than did the younger adults, $F(1, 99) = 35.21$,

$p < .05$. There were no age differences in self-reported computer experience ($p = .06$).

Performance (or the extent to which the participant could complete the task quickly and with few errors) was measured using three dependent variables: task completion time, mouse clicks, and errors. Only the responses in which the participant was able to reach the final answer were included in the analyses. For each performance measure, lower values indicated better performance. These measures were combined to create a composite dependent measure of information search performance (e.g., Chadwick-Dias et al., 2003) in which each variable was equally weighted. Creating composite performance variables in the context of usability evaluation has been suggested as a way to better express the meaningfulness of disparate usability metrics (Sauro & Kindlund, 2005) as well as to increase the stability and reliability of our measure (Dillon & McDonald, 2001).

Before creating a composite variable, we computed Cronbach's alpha reliability coefficient between our three dependent variables (task time, errors, and clicks) to verify that they measured a similar, stable, underlying construct. The coefficient ranges from 0 to 1, with higher values indicating that a measure is reliable. In the social sciences, measures with Cronbach's alpha values above .7 are considered highly reliable and consistent (Nunnaly, 1978). The value of Cronbach's alpha for the individual *z*-score-transformed dependent measures (*z* scores instead of raw scores because the procedure requires equivalent scales of measurement) indicated a value of .77, validating the combination of dependent variables into a single composite variable.

To create the performance composite, we transformed each dependent variable (task times, errors, clicks) to similar units of measurement (*z* scores with a mean of 0 and standard deviation of 1). These normalized values were then averaged to form a "composite performance" variable in which lower values indicated better performance, relative to higher values (Table 1).

A 2 (age group: young, old) × 2 (condition: tag based, taxonomy) ANOVA was conducted on the composite performance measure. The main effect of age was significant, $F(1, 96) = 5.96, p < .05, \eta_p^2 = .06$, with older adults having generally worse performance (larger *z*-score values) than younger adults.

Although the main effect of condition was not significant, the interaction of age and condition was significant, $F(1, 96) = 5.13, p < .05, \eta_p^2 = .05$, indicating that condition had different effects for each age group (Figure 3). The source of the interaction was that in the taxonomy condition, younger adults had significantly better performance than older adults, $F(1, 96) = 7.02, p < .05, \eta_p^2 = .10$. However, in the tag-based condition there were no significant age differences in performance, $F(1, 96) = .01, p > .05, \eta_p^2 = .00$. The presence of the Age × condition interaction suggests that the tag-based interface could moderate age-related differences in information search performance. To examine why older adults seemed to perform better with tag-based interfaces than with taxonomical interfaces, we next examined the relationships between abilities and performance.

Correlations. Correlations were computed to assess the relationships between abilities – specifically spatial abilities and vocabulary – and composite performance for each condition (Table 3). Correlations were computed separately for each condition. The individual measures of performance (task time, clicks, and error rate) were all significantly correlated with the composite measure (ranging from .67 to .92).

In the taxonomy condition, age was significantly correlated only with task completion time ($r = .73$) and errors ($r = .40$). The notable differences were that in the taxonomy condition, composite performance was significantly positively related with age ($r = .55$) and negatively related with perceptual speed ($r = –.46$), spatial orientation ($r = –.37$), and visualization abilities ($r = –.40$). The significant correlations with spatial ability in the taxonomy condition suggest that performance with hierarchical interfaces is associated with higher spatial ability, mirroring similar results in other studies (e.g., Pak et al., 2006; Seagull & Walker, 1992; Sein & Bostrom, 1989).

The pattern was very different in the tag-based condition, in which performance was significantly negatively related to computer experience level ($r = –.45$) and vocabulary ($r = –.36$). The significant negative relationship with computer experience may reflect the novelty of tag-based retrieval interfaces: The negative relationship indicates that higher computer experience levels were related to better performance. The significant correlation with vocabulary supports the assumption that tag-based retrieval interfaces may place more demands on vocabulary skill (crystallized intelligence) and

Continued on page 625

(a)

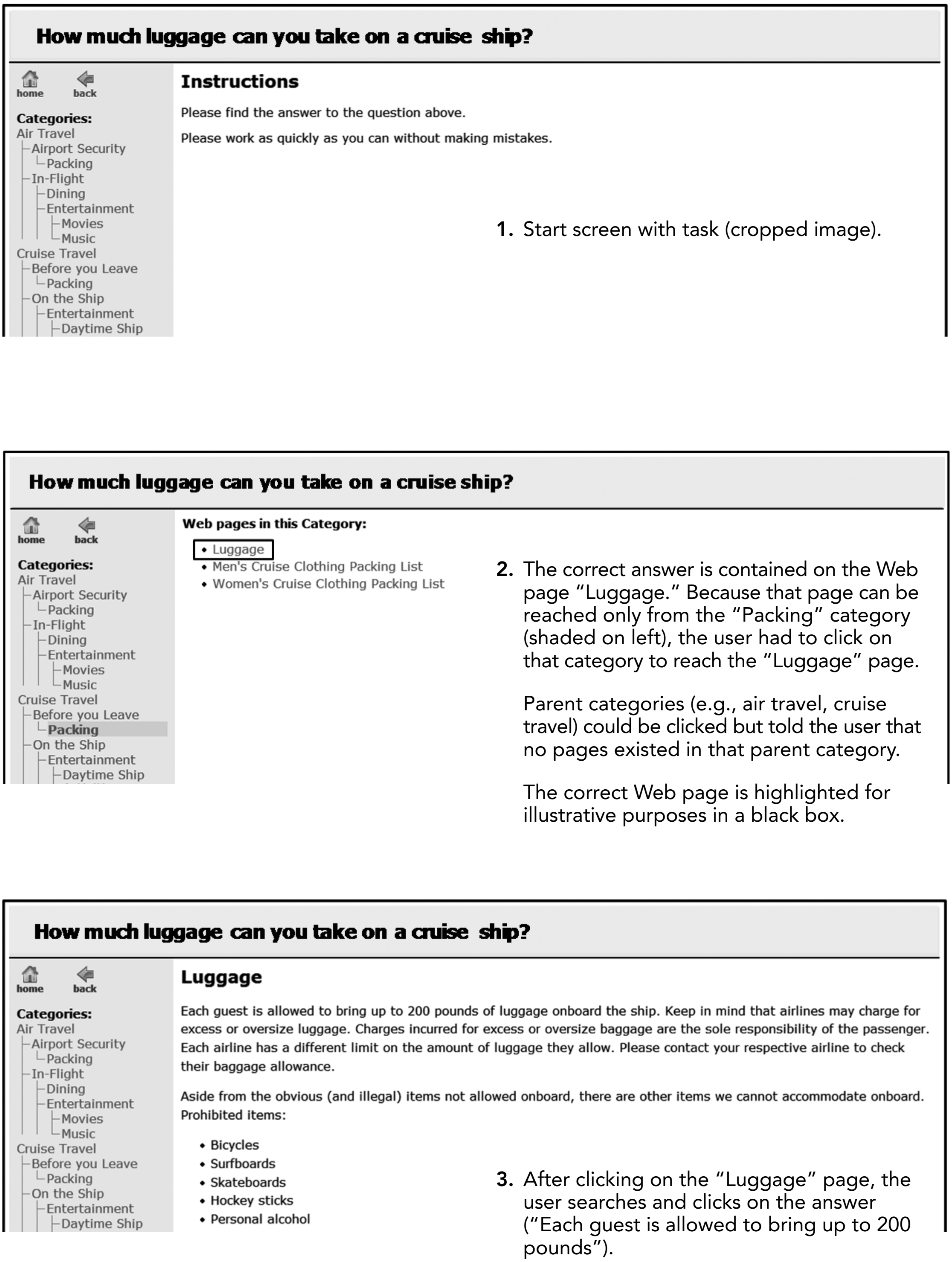
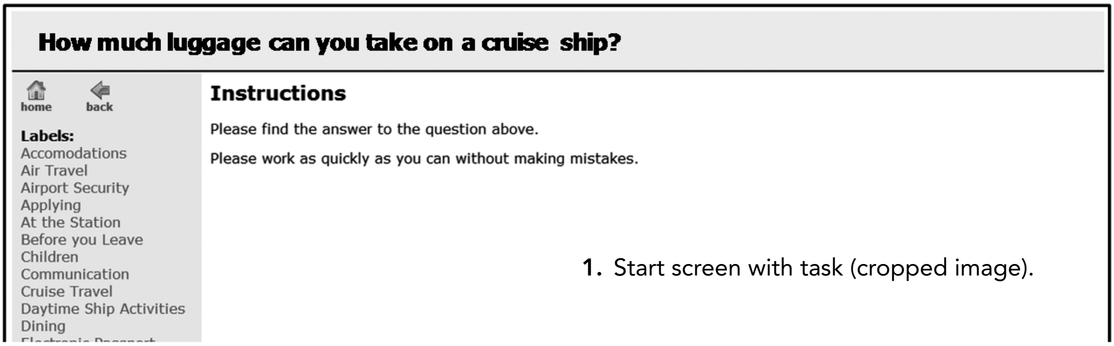
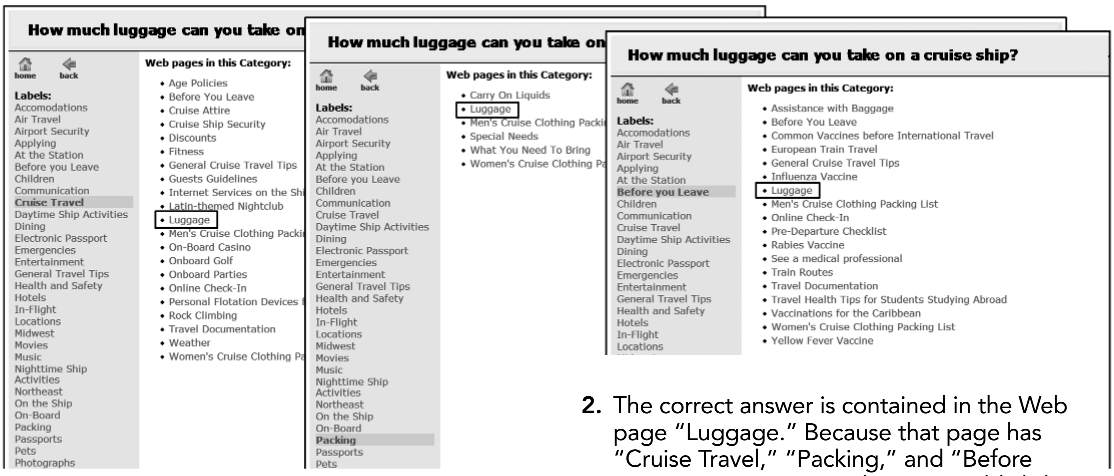


Figure 2 (above and facing page). Illustrations of each condition. (a) Taxonomic navigation condition. (b) Tag-based navigation condition. Instructions about the information to be retrieved were presented at the top, and the navigational tools (home and back button) and tags were presented on the left side. The active Web page was in the center.

(b)

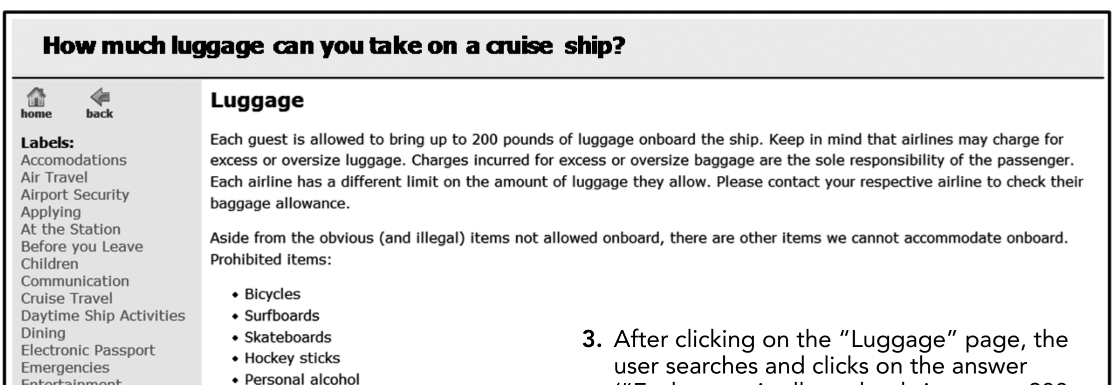


1. Start screen with task (cropped image).



2. The correct answer is contained in the Web page "Luggage." Because that page has "Cruise Travel," "Packing," and "Before you Leave" as its tags, the user could click any of those tags to reach the page.

The correct Web page is highlighted for illustrative purposes in a black box.



3. After clicking on the "Luggage" page, the user searches and clicks on the answer ("Each guest is allowed to bring up to 200 pounds").

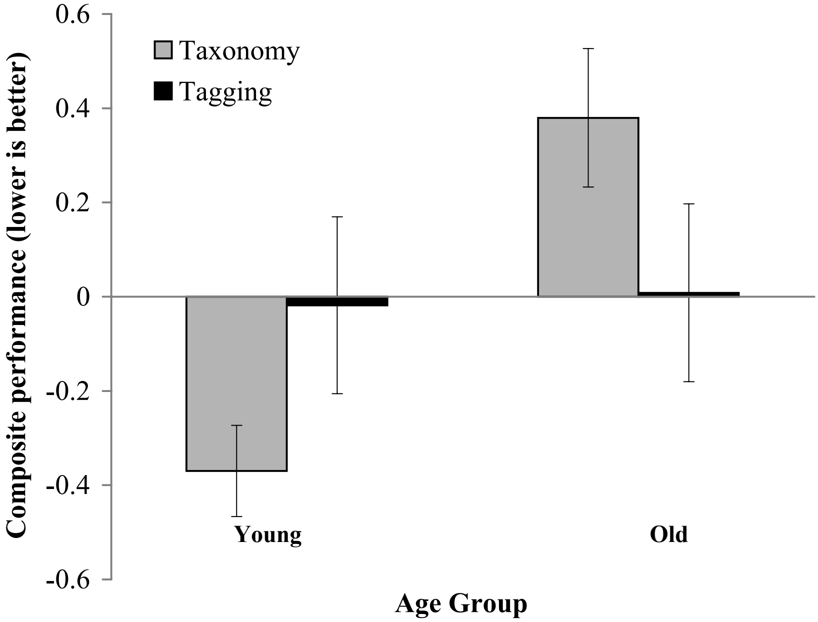


Figure 3. Mean composite performance as a function of age group and condition (error bars represent standard error).

TABLE 3: Correlations Between Abilities and Performance by Condition

		1	2	3	4	5	6	7	8	9	10	11
						Taxonomy (*N* = 50)						
1	Age	—										
2	Computer experience[a]	–.25	—									
3	Perceptual speed[b]	**–.57**	.03	—								
4	Memory span[c]	–.27	–.03	.21	—							
5	Spatial visualization[d]	**–.57**	.27	**.32**	.24	—						
6	Spatial orientation[e]	**–.41**	.11	**.41**	**.45**	**.31**	—					
7	Vocabulary[f]	**.52**	**–.31**	**–.31**	.02	**–.33**	.03	—				
8	Task completion time	**.73**	–.09	**–.61**	**–.32**	**–.53**	**–.48**	.19	—			
9	Clicks	.16	–.07	–.19	.07	–.16	–.08	–.19	**.46**	—		
10	Errors	**.40**	.04	**–.28**	**–.28**	–.15	**–.41**	–.10	**.58**	**.61**	—	
11	Composite performance	**.55**	–.06	**–.46**	–.22	**–.37**	**–.40**	–.01	**.86**	**.80**	**.84**	—
						Tag Based (*N* = 50)						
1	Age	—										
2	Computer experience[a]	–.15	—									
3	Perceptual speed[b]	**–.28**	.00	—								
4	Memory span[c]	–.21	–.01	–.13	—							
5	Spatial visualization[d]	**–.55**	.11	.13	**.36**	—						
6	Spatial orientation[e]	–.27	–.06	**.40**	**.30**	**.62**	—					
7	Vocabulary[f]	**.56**	.20	**–.30**	.14	–.02	–.03	—				
8	Task completion time	**.53**	**–.55**	–.19	**–.31**	**–.51**	–.27	–.05	—			
9	Clicks	–.24	**–.28**	.13	–.01	–.06	.17	**–.45**	**.40**	—		
10	Errors	–.10	**–.35**	.22	–.05	.04	**.29**	**–.36**	**.40**	**.84**	—	
11	Composite performance	.03	**–.45**	.08	–.13	–.18	.11	**–.36**	**.67**	**.91**	**.92**	—

Note. Bolded items indicate correlations significant at $p < .05$.

[a]Total length of computer experience on a scale of 1 (*less than 6 months*) to 5 (*greater than 5 years*). [b]Digit symbol substitution (number correct; Wechsler, 1997). [c]Reverse digit span (Wechsler, 1997). [d]Paper folding test (Ekstrom et al., 1976). [e]Cube comparison test (Ekstrom et al., 1976). [f]Shipley vocabulary test (Shipley, 1986). For all ability measures, higher equals better performance. For the performance measures, lower equals better performance.

less on spatial abilities. Surprisingly, performance was not significantly related to age ($r = .03$).

Hierarchical regressions. To determine which variables uniquely predicted performance, we conducted a hierarchical linear regression. In the hierarchical regression, predictors are entered in blocks or steps. Hierarchical regressions allowed us to examine unique performance by statistically controlling for the influence of variables entered in previous steps. Our hypothesis was that performance in the taxonomy condition would be predicted by spatial abilities, not vocabulary, whereas performance in the tag-based condition would be predicted by vocabulary, not spatial abilities, after we controlled for the influence of other variables.

Separate regressions were conducted for each condition (taxonomy and tag based; Table 4). Each step in the model tested the extent to which a particular ability accounted for significant variance in composite task performance after prior abilities were controlled for. Total variance accounted for is indicated by the R^2, whereas the variance accounted for by each newly added variable is indicated in the ΔR^2 column. The extent to which R^2 is increased (ΔR^2) indicates the importance of that variable in predicting age-related differences in performance. In Step 1, the first block of variables (computer experience, perceptual speed, and memory span) was entered together because we did not have specific hypotheses regarding the unique variance individually accounted for by these variables (i.e., used as control variables).

In addition, perceptual speed and memory span variables were included in the first block as proxies for age-related differences in reading and mouse movement speed. In the taxonomy condition, these variables accounted for 26% of the variance in performance. In the tag-based condition, the first block of variables accounted for only 7% of the variance in performance. After we controlled for experience, speed, and memory span, neither spatial visualization (Step 2) nor spatial orientation (Step 3) accounted for significant unique variance in performance in either condition. However, vocabulary (Step 4) did account for a significant increment in performance variance (15%), but only in the tag-based condition. Finally, age was entered into the regression model (Step 5). In the taxonomy condition, age was a significant predictor of performance (11%). However, in the tag-based condition the inclusion of age was not significant.

DISCUSSION

This study investigated whether age-related differences in information search performance could be improved by the use of an interface hypothesized to place greater demand on crystallized intelligence and accumulated knowledge than on fluid intelligence. The idea that crystallized intelligence associated with increasing age can potentially moderate declines in fluid intelligence is not new (e.g., Morrow & Leirer, 1996). However, these data suggest that the benefits of intact crystallized intelligence may help older adults in an information retrieval interface organized around tags, as compared with a taxonomically organized system.

In earlier work, we analyzed the cognitive processes involved in information-searching activities using a hierarchical and tag-based system (Figure 1). The proposed mechanism suggested that older adults' increased vocabulary knowledge could enhance their performance on the task of converting goals into search terms and selecting appropriate search terms in the interface. In addition, we believe that the presentation of information in the tag-based interface (with the many-to-one relationship, compared with taxonomy's one-to-one relationship) further enhanced the effect of good vocabulary by reducing the need to "start over" – that is, to restart the process by recreating a new search term.

The regressions showed that performance in the taxonomy condition was mostly predicted by a combination of prior experience, perceptual speed, and memory span, whereas performance in the tag condition was primarily predicted by vocabulary. Younger adults, with their higher perceptual speed and memory span, were particularly well suited for the taxonomy condition.

In addition, although the regressions did not show that spatial abilities uniquely predicted performance in the taxonomy condition, performance was significantly correlated with spatial abilities. Younger adults' significantly higher spatial abilities may have helped them navigate the hierarchy more efficiently than older adults. However, younger adults' lower vocabulary skills may have hindered their performance in the tag-based condition and provided older adults more support. Further, as illustrated in Figure 3 and shown in Step 5 of the regressions, a tag-based system was able to reduce the predictability of age on

TABLE 4: Summary of Hierarchical Regression Analysis Predicting Composite Task Performance

	Taxonomy					Tag Based				
Variable	R^2	ΔR^2	β	ΔF	p	R^2	ΔR^2	β	ΔF	p
Step 1	.263	**.263**		5.48	**.00**	.071	.071		1.18	.33
Computer experience			–.196					–.228		
Perceptual speed			–.395					.080		
Memory span			–.084					–.074		
Step 2	.285	.022		1.38	.25	.082	.011		0.54	.47
Computer experience			–.112					–.203		
Perceptual speed			–.360					.099		
Memory span			–.071					–.033		
Spatial visualization			–.181					–.118		
Step 3	.311	.026		1.68	.20	.146	.064		3.31	.08
Computer experience			–.106					–.171		
Perceptual speed			–.303					–.033		
Memory span			–.002					–.094		
Spatial visualization			–.158					–.318		
Spatial orientation			–.197					.368		
Step 4	.354	.043		2.86	.10	.297	**.151**		9.22	**.00**
Computer experience			–.149					–.202		
Perceptual speed			–.374					–.168		
Memory span			.017					–.053		
Spatial visualization			–.211					–.346		
Spatial orientation			–.142					.418		
Vocabulary			–.236					–.413		
Step 5	.469	**.114**		9.05	**.00**	.303	.006		0.36	.56
Computer experience			–.047					–.171		
Perceptual speed			–.219					–.148		
Memory span			.038					–.036		
Spatial visualization			–.090					–.272		
Spatial orientation			–.051					.390		
Vocabulary			–.411					–.483		
Age			.552					.137		

Note. Bolded items indicate significant increments/predictors. The R^2 indicates the total variance accounted for with the inclusion of each step. The ΔR^2 indicates the change in total R^2 attributable to the inclusion of a step. The ΔF statistic indicates the change in F associated with the inclusion of each block of variables.

performance, as compared with a taxonomically organized system.

In the taxonomy, pages were accessible from only a single location (menu option). This one-to-one relationship between menu and page is contrasted with the tag-based condition, in which the relationship between menu options and pages was many to one. Thus, participants who had better vocabulary may have been more likely to be able to formulate the correct tag or keyword, search for the specific tag, and reach the desired page in the tag-based condition than in the taxonomy condition (see Figure 2b).

Although the taxonomy condition was hypothesized to demand high spatial abilities, the regressions showed that this was not the case after we controlled for more basic abilities. Spatial visualization or orientation did not account for significant unique variance in performance, although performance in the taxonomy condition was significantly correlated with spatial ability.

This may be attributable to the design of the condition. In prior research in hierarchical menu searching, items contained within the hierarchy were hidden (i.e., users first had to select an item to view its contents). In the current study, to equalize the presentation of information, all menu items were fully expanded. This is illustrated in Figure 2a, in which the menu and submenus are fully visible by default. In this configuration, spatial ability and memory demands may have been reduced. Nonetheless, performance differences were observed between conditions. Although spatial ability did not predict performance in either condition, as we hypothesized, vocabulary was predictive of performance in the tag-based condition only – and older adults' increased vocabulary may have allowed them to use the tag-based interface more efficiently than the taxonomy interface.

Concerning the role of crystallized intelligence, we specifically chose a task domain that was hypothesized to be similar in familiarity for both age groups (travel information). Although our previous study showed that both younger and older adults conceptualized travel information similarly, this finding should be validated in future studies. More generally, given the current results, a strong hypothesis that may follow is that under conditions where older adults have relatively more knowledge of a topic than younger adults, performance benefits in a tag-based condition should be even greater (i.e., older adults should perform better than younger adults). Future studies should examine how the current findings are modified in a domain presumed to be more familiar to older adults (e.g., health or financial information). Under these conditions, older adults may be more able to draw upon their domain knowledge to help them find information.

Finally, this study was concerned primarily with the situation in which a visitor to a Web site encountered information that had already been organized (in a taxonomy or tag-based system) and participants in the study had no input. It is important to note that this type of condition may represent an idealized situation in comparison with production tag-based systems used on the Internet. Thus, we are limited in our ability to make specific design recommendations.

In many systems, participants are able to generate their own tags or taxonomies. Our prior study (Pak et al., 2007) showed a modest retrieval performance advantage (fewer mouse clicks) when younger adults generated their own tags as compared with when they generated their own taxonomy. However, young adults took longer to initially organize information when using a tag-based system, compared with a taxonomy. Given the current findings, future studies should examine how information organization and retrieval performance is affected when older adults organize the information themselves by applying their own tags.

CONCLUSION

To maximize successful access to information technologies, older adults must be able to use computer-based systems quickly and efficiently. The current results demonstrate that some aspects of older adults' information retrieval performance may be enhanced when the information is organized around a tag-based system that places more demand on vocabulary knowledge. It is premature to suggest design implications, but the current results point to the need for more research examining the specific conditions under which older adults' information search performance can be enhanced.

ACKNOWLEDGMENTS

Thanks to Steven Pautz, Amanda Trujillo, Abe Webber, and Mary-Catherine McClain for assistance in collecting data. We are also grateful to three anonymous reviewers and Wendy Rogers, Marita O'Brien, and Lee Gugerty for their comments on earlier drafts. A preliminary version of this study was presented at the 2007 Human Factors and Ergonomics Society meeting with proceedings (Pautz, Price, & Pak, 2007).

REFERENCES

Chadwick-Dias, A., McNulty, M., & Tullis, T. (2003). Web usability and age: How design changes can improve performance. In *Proceedings of the 2003 Conference on Universal Usability* (pp. 30–37). New York: Association for Computing Machinery Press.

Chen, C., & Rada, R. (1996). Interacting with hypertext: A meta-analysis of experimental studies. *Human-Computer Interaction, 11,* 125–156.

Craik, F. I. M., & Salthouse, T. A. (2000). *The handbook of aging and cognition* (2nd ed.). Mahwah, NJ: Erlbaum.

Czaja, S. J., Charness, N., Fisk, A. D., Hertzog, C., Nair, S. N., Rogers, W. A., et al. (2006). Factors predicting the use of technology: Findings from the Center for Research and Education on Aging and Technology Enhancement (CREATE). *Psychology and Aging, 21,* 333–352.

Czaja, S. J., Charness, N., Fisk, A. D., Rogers, W., & Sharit, J. (2001). The Center for Research and Education on Aging and Technology Enhancement: A program for enhancing technology for older adults. *Gerontology, 1,* 50–59.

Dillon, W. R., & McDonald, R. (2001). Methodological and statistical concerns of the experimental behavioral researcher. *Journal of Consumer Psychology, 10,* 62–64.

Dong, J., Martin, S., & Waldo, P. (2001). A user input and analysis tool for information architecture. In *Proceedings of the 2003 SIGCHI Conference* (pp. 23–24). New York: Association for Computing Machinery Press.

Ehrlich, K. (1996). Applied mental models in human-computer interaction. In J. Oakhill & A. Garnham (Eds.), *Mental models in cognitive science* (pp. 223–245). Mahwah, NJ: Erlbaum.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests.* Princeton, NJ: Educational Testing Service.

Garfein, A. J., Schaie, K. W., & Willis, S. L. (1988). Microcomputer proficiency in later-middle-aged and older adults: Teaching old dogs new tricks. *Social Behavior, 3,* 131–148.

Hawthorn, D. (2000). Possible implications of aging for interface designers. *Interacting with Computers, 12,* 507–528.

Horn, J. L. (1982). The theory of fluid and crystallized intelligence in relation to concepts of cognitive psychology and aging in adulthood. In F. I. M. Craik & S. E. Trehub (Eds.), *Aging and cognitive processes* (pp. 847–870). New York: Plenum Press.

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26,* 107–129.

Kausler, D. H. (1991). *Experimental psychology, cognition, and human aging* (2nd ed.). New York: Springer-Verlag.

Laberge, J. C., & Scialfa, C. T. (2005). Predictors of Web navigation performance in a life span sample of adults. *Human Factors, 47,* 289–302.

Morrow, D., & Leirer, V. (1996). Aging, pilot performance, and expertise. In A. D. Fisk & W. A. Rogers (Eds.), *Handbook of human factors and the older adult* (pp. 199–230). San Diego, CA: Academic Press.

Nunnaly, J. (1978). *Psychometric theory.* New York: McGraw-Hill.

Pak, R., Mayhorn, C. B., Stronge, A. J., & Padgett, L. (2002, April). *Reviewing Website usability: Information organization.* Paper presented at the 13th Annual Southeastern Regional Student Convention in Gerontology and Geriatrics, Athens, GA.

Pak, R., Pautz, S., & Iden, R. (2007). Information organization and retrieval: An assessment of taxonomical and tagging systems. *Cognitive Technology, 12*(1), 31–44.

Pak, R., Rogers, W. A., & Fisk, A. D. (2006). Spatial ability subfactors and their influences on a computer-based information search task. *Human Factors, 48,* 154–165.

Pautz, S. L., Price, M. M., & Pak, R. (2007). Accommodating age-related differences in computer-based information retrieval tasks. In *Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting* (pp. 1471–1475). Santa Monica, CA: Human Factors and Ergonomics Society.

Pew Internet & American Life Project. (2005, October). *Digital divisions: There are clear differences among those with broadband connections, dial-up connections, and no connections at all to the Internet.* Retrieved June 9, 2008, from http://www.pewinternet.org/PPF/r/165/report_display.asp

Pew Internet & American Life Project. (2006, March). *Online news: For many home broadband users, the Internet is a primary news source.* Retrieved June 9, 2008, from http://www.pewinternet.org/pdfs/PIP_News.and.Broadband.pdf

Redish, J., & Chisnell, D. (2004). *Designing Web sites for older adults: A review of recent research.* Retrieved June 9, 2008, from http://assets.aarp.org/www.aarp.org_/articles/research/oww/AARP-LitReview2004.pdf

Sauro, J., & Kindlund, E. (2005). A method to standardize usability metrics into a single score. In *Proceedings of CHI 2005* (pp. 401–409). New York: Association for Computing Machinery.

Schaie, K. W. (1996). *Intellectual development in adulthood: The Seattle longitudinal study.* New York: Cambridge University Press.

Seagull, F. J., & Walker, N. (1992). The effects of hierarchical structure and visualization ability on computerized information retrieval. *International Journal of Human-Computer Interaction, 4,* 369–385.

Sein, M. K., & Bostrom, R. P. (1989). Individual differences and conceptual models in training novice users. *Human-Computer Interaction, 4,* 197–229.

Shipley, W. (1986). *Shipley Institute of Living Scale.* Los Angeles: Western Psychological Press.

Stanney, K. M., & Salvendy, G. (1995). Information visualization: Assisting low spatial individuals with information access tasks through the use of visual mediators. *Ergonomics, 38,* 1184–1198.

Vicente, K. J., Hayes, B. C., & Williges, R. C. (1987). Assaying and isolating individual differences in searching a hierarchical files system. *Human Factors, 29,* 349–359.

Vicente, K. J., & Williges, R. C. (1988). Accommodating individual differences in searching a hierarchical file system. *International Journal of Man-Machine Studies, 29,* 647–668.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale* (3rd ed.). San Antonio, TX: Psychological Corp.

Weinberger, D. (2007). *Everything is miscellaneous: The power of the new digital disorder.* New York: Times Books.

Westerman, S. J. (1997). Individual differences in the use of command line and menu computer interfaces. *International Journal of Human-Computer Interaction, 9,* 183–198.

Richard Pak is an assistant professor in the Department of Psychology at Clemson University, Clemson, South Carolina. He received his Ph.D. in psychology in 2005 from the Georgia Institute of Technology.

Margaux Price is a research assistant at Clemson University, where she received her B.A. in psychology in 2007.

Date received: October 29, 2007
Date accepted: June 6, 2008